Potato Diversity at Height:

multiple dimensions of farmer-driven *in-situ* conservation in the Andes

Stef de Haan

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to Andean farmers and their legacy
for Rosa and Milena

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1. Introduction

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1.1 Justification

On-farm or *in-situ* conservation has become a well established and recognized approach for crop genetic resource conservation (Almekinders and De Boef, 2000; Bretting and Duvick, 1997; Brush, 1989, 2000; Engels *et al.*, 2002; Friis-Hansen, 1999; Henry, 2006; Partap and Sthapit, 1998; Smale, 1998; Wood and Lenné, 1999). A few decades ago, at the start of the green revolution, it was considered inevitable that modern cultivars[1] from breeding programs would almost completely replace native cultivars maintained by farmers in centers of crop origin (Brush, 2004). However, the "wipe out" doom scenario did not fully fulfill itself and millions of farmers around the world still actively grow and maintain ancestral cultivars of diverse crop species. Nowadays *in-situ* conservation is valued as complementary to global *ex-situ* conservation. It supports ongoing crop evolution while maintaining dynamic indigenous knowledge systems that surround crop genetic resources (Frankel *et al.*, 1995; Maxted *et al.*, 1997; Soleri and Smith, 1999). The theoretical, conceptual and developmental framework of *in-situ* conservation is still evolving but has advanced considerably during the last decade (Alvarez *et al.*, 2005; Bellon, 2001, 2004; Brush, 2004; CIP-UPWARD, 2003; de Boef, 2000; Jarvis *et al.*, 2000a, 2000b; Maxted *et al.*, 1997; Maxted *et al.*, 2002).

Brush (2000) distinguishes between two types of *in-situ* conservation. First, the persistence of crop genetic resources in areas where everyday practices of farmers maintain diversity on their farms. This type of *in-situ* conservation is "farmer-driven" and both a historical and ongoing phenomenon (Brush, 2000; Zimmerer, 1993). The second type concerns Research & Development (R&D) strategies designed to foment *in-situ* conservation by farmers. This type of *in-situ* conservation is "externally driven" and implemented by special projects, NGO's and governmental agencies, among others. The two types of *in-situ* conservation are connected in the sense that the success of externally driven strategies arguably depends on a good understanding of farmer-driven *in-situ* conservation. The other way around, the impact of externally driven strategies on farmer-driven *in-situ* conservation should preferably be well understood so that R&D interventions can become increasingly intelligent and targeted.

1.2 Conceptual framework

This thesis investigates multiple dimensions of farmer-driven *in-situ* conservation of the cultivated potato and the contemporary context in which it takes place. A main difference

[1] The term "cultivar" is used throughout this thesis and is defined as "an assemblage of plants that has been selected for a particular attribute or combination of attributes, and that is clearly distinct, uniform and stable in its characteristics and that, when propagated by appropriate means, retains those characteristics (Brickell *et al.*, 2004)". A cultivar can either be ancestral (synonymous to: native, traditional or indigenous landrace or variety) or modern (synonymous to: improved or high-yielding variety).

between *in-situ* conservation efforts focusing on crop wild relatives and cultivated genetic diversity relates to the inherent anthropogenic nature of the latter. Fundamentally, cultivated genetic diversity cannot be maintained *in-situ* without its active management by man while crop wild relatives are ideally left uninterrupted without human interference (e.g. habit destruction) which would put at risk their long term survival (Heywood *et al*., 2007; Jarvis *et al*., 2008; Maxted *et al*., 2008). It is doubtful that conservation *perse* motivates most farmers to maintain high levels of potato genetic diversity. Nevertheless, there are indications that individual farmers may accumulate and maintain diversity for "conservation" purposes. However, in general, farmer-driven *in-situ* conservation can be seen as the outcome of livelihood strategies that actively use and rely on crop genetic diversity (Brush, 2004).

In this study, farmer-driven *in-situ* conservation of potato, i.e. that which is being grown by farmers, is investigated at different system levels from alleles, cultivars, and botanical species up to agroecology as well as overarching links to seed and food systems. The dimensions of time and space are inferred upon by taking into account both annual and longer-term spatial patterns within the Andean environment. The thesis also aims to link the diversity found in farmers' fields and its temporal-spatial distribution to a series of farmer-based drivers, such as changes in land use, and external drivers, e.g. biotic and abiotic stress and markets. Components of farmer-driven *in-situ* conservation are "mirrored" against each other to gain insights into their relationships, e.g. formal versus indigenous biosystematics and *in-situ* versus *ex-situ* conservation. The study of these different elements of farmer-driven *in-situ* conservation of the potato is multidisciplinary in its basic conceptual approach and integrates different methodologies and tools while focusing on the selected dimensions described below.

1.2.1 Inventory of diversity

While distribution patterns of cultivated potato species are well defined (Correll, 1962; Hawkes, 1990; Hawkes and Hjerting, 1989; Huaman and Spooner, 2002; Ochoa, 1990, 1999, 2003; Sauer, 1993), the same is not true for the fine grained scale of cultivar diversity. Andean farmers in Peru are estimated to conserve up to 3,000 distinct native cultivars based on passport data from the world potato genebank held at the International Potato Center. However, beyond the general notion that cultivar diversity is particularly high in the central and southern Peruvian Andes, little is known about the contemporary distribution of infraspecific diversity within specific regions. The characterization and comparison of populations of native cultivars being maintained through farmer-driven *in-situ* conservation is important in order to define the "object of conservation" (Brush *et al*., 1995). This is affirmed by Maxted and Hawkes (1997) when they point out that "as a matter of urgency, a chain of genetic reserves to conserve cultivated potatoes should be established throughout the Andes in areas with high levels of genetic diversity".

Cultivar populations in the hands of farmers in Vavilov centers of crop origin and diversity are commonly reported to be subject to genetic erosion resulting in the loss of alleles (Frank *et al*., 2002; Harlan, 1975; Ochoa, 1975) and ongoing evolution leading to the gradual creation of new genotypes or alleles (Altieri, 1987a, 1987b; Mann, 2004; Maxted *et al*., 1997; Vavilov, 1992). The occurrence of genetic erosion, when defined as the loss of alleles and gene complexes from *in-situ* populations, is generally difficult to substantiate because of a lack of baseline data needed for comparison over a sufficient timeframe (Brush, 2004). Therefore relatively few studies have been able to provide quantitative evidence to sustain or reject the occurrence of genetic erosion (e.g. Huang *et al*., 2007). Differences between the contents and structures of genebank collections and contemporary cultivar populations in the hands of farmers, from the same geographical origin, are little known (for an exception concerning wild potato species see Del Rio *et al*., 1997).

1.2.2 Farmers' classification

A better understanding of the interface between researcher and farmer systems of agrobiodiversity classification can provide important insights that are essential for *in-situ* conservation of crop genetic diversity (Bellon *et al.*, 1998; Emshwiller, 2006; Laird, 2002; Nuijten and Almekinders, 2008; Orlove and Brush, 1996; Tamiru, 2006). In order to understand how farmers perceive the "object of conservation" it is important to enhance our understanding of the way farmers themselves classify, distinguish and name agrobiodiversity. Three levels of inquiry can be distinguished. First, folk taxonomy or the recognition of folk ranks and taxa (Berlin, 1992). Such classifications have been proposed for the cultivated potato in the Andes, but differ among each other (e.g. Brush, 1980; La Barre, 1947; Zimmerer, 1996). Second, folk descriptors used to recognize and distinguish among distinct cultivars. This fine grained level of classification has generally received little attention, but is potentially valuable as it represents the local knowledge necessary to distinguish between the principal units of *in-situ* conservation: cultivars. Third, indigenous nomenclature involving the ethnolinguistic structure of vernacular cultivar names and its inherent logic and consistency. With few exceptions (e.g. Quiros *et al.*, 1990), the relation between formal and farmer systems of classification of the potato in its center of origin have been little studied.

1.2.3 Land use practices and patterns

The Andean cropping environment is extremely diverse and farmers often manage multiple production zones (Lehman, 1982; Mayer, 1981; Murra, 2002; Terrazas and Valdivia, 1998). An adequate understanding of the logic underlying the annual and long-term temporal-spatial dynamics of cultivated agrodiversity managed by man is important in order to potentially spot tendencies and trends which may be detrimental or favorable for conservation. Cropping calendars, field scattering practices and environmental adaptation determine the yearly spatial patterning of diverse genotypes while long-term spatial dimensions and changes are potentially reflected in land use changes (Halloy *et al.*, 2006; Zimmerer, 1999). Selected temporal and spatial dimensions have been researched at the species level (e.g. Brush, 1977; D'Altroy, 2000). Yet, they have been relatively little investigated at the infraspecific level where conservation units (genotypes, cultivars) are particularly relevant for *in-situ* conservation (for exceptions see Perales *et al.*, 2003; Zimmerer, 1998, 1999).

1.2.4 Farmer seed systems

Native cultivars of diverse Andean crops, including the potato, are predominantly reproduced and exchanged through farmer seed systems (Ezeta, 2001; Thiele, 1999). Understanding the nature and operations of farmer seed systems is central to the *in-situ* conservation of infraspecific diversity (Hodgkin and Jarvis, 2004); partially because these systems potentially supply seed of biodiverse cultivars and acceptable quality widely through decentralized mechanisms (Almekinders and Louwaars, 1999; Bertschinger, 1992; Thiele, 1999; Tripp, 2001; Zimmerer, 2006). The farmer seed system partially determines the efficiency and sustainability of farmer-driven *in-situ* conservation as seed health, availability and distribution patterns characterize the long term viability of diverse cultivar populations. Little is known about the organization of seed stores and how this is related to the infraspecific diversity farmers maintain. The same is true for the phytosanitary status of biodiverse farmer produced seed of Andean tuber crops (for exceptions see Bertschinger, 1992; Bertschinger *et al.*, 1990). Seed procurement through social networks is an important characteristic of farmer seed systems (Badstue, 2006; Badstue *et al.*, 2005; Boster, 1986). Yet, there is a general knowledge gap concerning the cultivar contents of predominant seed flows and how relative cultivar richness varies by events or mechanism, e.g. direct farmer-to-farmer exchange or transactions at regular market or biodiversity seed fairs. Resilience has been reported as one of the key characteristics of farmer seed systems (Sperling *et al.*, 2008). However, how farmers cope with severe shocks to seed systems in areas where high levels of cultivar diversity are conserved remains relatively underexplored.

1.2.5 Food systems

Long-term farmer-driven *in-situ* conservation of crop genetic diversity is most likely best sustained by usefulness and actual use of the genetic resources in question. It is therefore likely that use rationales are primary drivers underlying farmer-driven *in-situ* conservation. The diversity of uses of infraspecific diversity is often particularly rich in the centres of crop origin and diversity (Sandstrom, 1991; Schultes and Von Reis, 1995). The most obvious use of crop genetic diversity is embedded within subsistence food systems (Graham *et al.*, 2007), even though agroecosystem services, medicinal, ritual and other uses may provide additional use value (Collins and Qualset, 1998; Jarvis *et al.*, 2007; Valdizán and Maldonado, 1922). The role of infraspecific diversity within subsistence food systems as expressed through variability of the nutrient content of native cultivars, dietary intake of infraspecific diversity and culturally established preference traits merits exploration. Links drawn between biodiversity and nutrition generally focus on species rather than cultivar diversity (e.g. Toledo and Burlingame, 2006). Relatively little attention has been given to the potential role of infraspecific diversity and its contribution to food security (Johns, 2002; Johns *et al.*, 2006; Thrupp, 2000).

1.3 Research questions and thesis objective

The research presented in this thesis specifically focuses on farmer-driven *in-situ* conservation in order to obtain a better understanding of what it is that farmers conserve, how farmers themselves classify agrobiodiversity of the potato, how infraspecific diversity is temporally and spatially patterned within the agricultural landscape and through farmer seed system management, and the role of infraspecific diversity from a use-perspective with particular emphasis on food systems and human nutrition.

General and specific research questions follow from the conceptual framework and, differentiating between the different system components and dimensions maintained throughout the thesis, read as follows:

1. What is it that farmers conserve from a formal biosystematics perspective? How many cultivated potato species and cultivars are conserved at different population levels? How does the population structure of a large contemporary *in-situ* collection compare to a geographically restricted *ex-situ* core collection?
2. How do Andean Quechua farmers themselves classify, distinguish and name agrobiodiversity of the potato from an indigenous biosystematics perspective? What is the system of folk taxonomy, folk descriptors and indigenous nomenclature commonly applied to infraspecific diversity of the potato?
3. What characterizes the contemporary annual spatial management of potato infraspecific diversity? How are the potato cropping and labor calendars patterned? How do field scattering practices relate to farmer employment of cultivar diversity? Is differential management of native cultivars based on niche adaptation?
4. How do land use changes affect the temporal-spatial distribution of potato infraspecific diversity? Are current land use tendencies and variations of household-based and sectoral rotation designs detrimental or favorable for continued *in-situ* conservation of infraspecific diversity?
5. How do farmer seed system components relate to infraspecific diversity? How are seed stores organized and does this reflect rationales underlying differential management at the field level? Do viruses limit seed health of native cultivars? How does seed procurement of native cultivars take place and what are the roles of markets and seed fairs? Is the farmer seed system able to respond to severe shocks?

6. What is the role of potato and its infraspecific diversity within the human diet? Do different cultivar categories[2] contribute evenly to the highland diet? What are the most notable cultural particulars of potato infraspecific diversity within the Andean food system?

Taking these questions into account the overall objective of this study is to enhance our understanding of farmer-driven *in-situ* conservation of potato infraspecific diversity and the context in which it takes place. This in turn will hopefully provide useful lessons for R&D interventions which aim to foment and support conservation in balance with farmer's own ongoing maintenance of infraspecific diversity as part of their livelihood strategies. To incorporate variable *in-situ* crop-conservation programs into development planning for montane regions requires thoroughly assessing the contingent conditions for continued production (Zimmerer, 1992).

1.4 Research methods

Field research was conducted between October 2003 and September 2006 within the framework of the project "Conservation and Sustainable Use of the Agrobiodiversity of Native Potatoes" financed by the Government of Spain through its National Institute of Research on Agrarian and Food Technology (INIA) and implemented by the International Potato Center's Germplasm Enhancement and Crop Improvement division (CIP - GECI). The implementation of the project was coordinated by the author of this thesis with the active collaboration of numerous colleagues from different disciplinary backgrounds and a permanent team of two Quechua speaking fieldworkers. A combination of different methods was used to investigate selected dimensions of farmer-driven *in-situ* conservation. The methods are described in general in this introductory chapter, and a more detailed description of materials and methods is offered in each of the research chapters of this thesis.

1.4.1 Germplasm collection

Germplasm used in the research was obtained from farmer families and collections were maintained on the fields of these same families. Accessions taken to greenhouse facilities for microscopy, flow cytometry, double checking of species identification and ELISA tests (Enzyme-Linked Immunosorbent Assay) were eliminated after laboratory work (chapters 2 and 6). The previously reported species *Solanum phureja* (Ochoa, 2003, p.56-57) was not encountered within the farmer family collections accessed. Therefore, two collections trips (2005) were undertaken to specifically search for *S. phureja* (chapter 2).

1.4.2 On-farm trials

On-farm field trials were conducted in close collaboration with farmer families. During three subsequent agricultural seasons (2003-2006) a total of 38 on-farm trials for the characterization of farmer family *in-situ* populations of native cultivars were conducted (chapter 2). A genotype by environment (GxE) experiment was conducted (2004-2005) following an altitudinal transect along a slope in one highland community. A total of 31 cultivars were planted in four altitude differentiated environments covering an altitude amplitude of 574 m to investigate levels of microhabitat adaptation (chapter 4).

[2] The term "cultivar categories" is used throughout this thesis and refers to three categories commonly recognized by Andean farmer and which, at the same time, typically coincide with a complex of botanical species: 1. native-floury cultivars (*S. tuberosum* subsp. *andigena*, *S. chaucha*, *S. stenotomum* and *S. goniocalyx*), 2. native-bitter cultivars (*S. juzepczukii*, *S. ajanhuiri*, *S. curtilobum*), 3. improved cultivars (*S. tuberosum* subsp. *tuberosum*).

1.4.3 Greenhouse facilities

In order to facilitate microscopy, flow cytometry and double checking of species identification (chapter 2), duplicates of most farmer family *in-situ* populations were installed in greenhouses at the International Potato Center's (CIP) experimental stations La Molina and Santa Ana in Lima and Huancayo respectively. Greenhouse facilities were also used to grow plants from farmer tuber seed samples of multiple native cultivars in order to determine the presence of viruses (chapter 6).

1.4.4 Laboratory

Laboratory facilities at the International Potato Center (CIP) were used for high throughput genotyping, microscopy and flow cytometry (chapters 2 and 3). ELISA tests (Enzyme-Linked Immunosorbent Assay) for selected potato viruses (APMoV, PLRV, PMTV, PVY and PVX) were conducted in CIP´s virology laboratory in order to determine virus infection rates within seed stocks of diverse native cultivars (chapter 6). The nutrient contents (dry matter, energy, protein, iron and zinc) of frequently consumed native-floury and native-bitter cultivars were determined using laboratory facilities and services of nutrition laboratories at CIP, the National Agrarian University La Molina (UNALM, Peru) and the University of Adelaide, Australia (chapter 7).

1.4.5 Characterization of *in-situ* cultivar populations

Farmer family *in-situ* populations of native cultivars were used for morphological and molecular characterization while ploidy levels determined through microscopy and flow cytometry in combination with morphological keys were used to determine botanical species (chapter 2).

1.4.6 Surveys

A series of semi-structured surveys were conducted during and after the 3-year period of field research (2003-2006):

1. A baseline survey to obtain basic demographic information about the research communities (2003-2004).
2. A survey to characterize the annual potato cropping and labor calendars (2004-2005; chapter 4).
3. A survey inquiring about two separate periods of seed exchange (acquisition and provision) of native cultivars by farmers (2004; chapter 6).
4. A survey at regular markets aimed to gain insight into the role of markets for seed provision of native cultivars (2005; chapter 6).
5. A survey at biodiversity seed fairs to gain insight into the role of fairs for seed provision of native cultivars (2005-2006; chapter 6).
6. An additional survey designed to characterize seed procurement following a severe regional out-off-season frost resulting in seed stress (2007-2008; chapter 6).
7. Participatory poverty analysis workshops and surveys following an adapted "stages of progress" methodology (2005; chapter 7).

1.4.7 Sampling exercises

A participatory "field scattering" sampling and cartography exercise was implemented (2004-2005) to determine the cultivar content and georeference potato fields of 122 households from 8 communities. The data obtained was used to determine the annual altitude-determined spatial arrangements of cultivars categories and individual cultivars (chapter 4). Sampling exercises were conducted in farmer seed stores (2004-2005) in order to determine how stores are internally organized and how this relates to the maintenance and management of infraspecific diversity (chapter 6). Random tuber seed samples of each native cultivar belonging to 22 conservationist farmers were used to determine virus infection rates (chapter 6).

1.4.8 Ethnobotanical inquiry

Folk taxonomy of the potato was researched through grouping exercises with farmer families, participant observation, and comparison of farmer-recognized groups with formal classification (chapter 3). The use of folk descriptors by Quechua farmers for above- and below ground plant parts was investigated by applying free- and indicated listing exercises in farmer fields and stores (chapter 3). Further, native cultivar nomenclature was researched applying a nomenclature survey with regional fixed cultivar samples, basic ethnolinguistic analysis of regional names and participant observation (chapter 3). Participant and ethnographic observation as a research methodology was used to investigate selected cultural connotations underlying the consumption of diverse rather than single potato cultivars (chapter 7).

1.4.9 Participatory cartography

Participatory cartography, also commonly referred to as participatory GIS, was applied (2005-2006) to investigate selected elements of land use and their relation to *in-situ* management of infraspecific diversity of the potato: land use tendencies between 1995 and 2005, rotation designs and intensity from 1995 till 2005, and the evolution of sectoral fallow systems between 1975 and 2005 (chapter 5).

1.4.10 Nutrition and dietary intake

A food intake study was conducted in order to quantify and characterize the contribution of potato and other food sources to the diet of children between 6 and 36 months of age and their mothers (2004-2005). The specific method consisted of direct measurement of food intake by weight during a 24 hour period for each of 77 households (mothers and children) during two contrasting periods: relative food abundance versus food scarcity (chapter 7). Additionally, the overall nutritional status of 340 children was determined at schools through the registration of age and measurement of weight and height (chapter 7).

1.4.11 Research ethics

Agreements of previous informed consent were signed between the research communities and the International Potato Center (CIP) in accordance with Peru's legislation concerning the regime of protection of the collective knowledge of indigenous peoples related to biological resources (law 27811). In case of particular studies, such as the food intake study, agreements of previous informed consent were signed with each participating household. All the results of the research were shared with the communities and participating households (see CIP, 2006; Anderson and Winge, 2008, pp. 23-25).

1.5 Study area

The study of crop genetic resources is especially valid in areas of crop domestication, where diversity is concentrated and where farmers maintain native cultivars of ancestral crop populations and the human knowledge and practices that have shaped this diversity for generations (Brush, 1991). The department of Huancavelica in the central Peruvian highlands is such an area, where native Andean crop species, their wild relatives and indigenous Quechua farmers have coexisted for centuries.

1.5.1 A brief history

Huancavelica was founded in 1572 after the Spanish conquistadores learned of the existence of a mercury mine in 1564 from a local Indian called Ñahuincopa (Carrasco, 2003). The mining center of Santa Barbara became the principal supplier of mercury in Latin America and was essential for the exploitation of silver in colonial mining centers such as Potosi in Bolivia (Contreras, 1982).

Till today Huancavelica is known as "*La Villa Rica de Oroposa*" (the rich town of mercury; see Salas Guevara, 1993). Huancavelica's history as a mining center from 1564 till 1786 represents more than two centuries of Indian exploitation and genocide. The mine had the highest mortality rate in the whole of Latin America because of the toxicity of mercury and inhumane working conditions (Brown, 2001; Whitaker, 1941). The Spanish elite recruited its workforce by forcing local Indians to work. Indians were "recruited" on the countryside, chained and put to work as slaves at a time when the region had already been affected by demographic collapse as a consequence of disease (Cook, 1981).

After the closure of the Santa Barbara mine the fate of Huancavelica´s indigenous population continued to be plagued with oppression. Most of its territory was managed by large haciendas belonging to the colonial and mestizo elite (Carrasco, 2003; Favre, 1976; Sabogal, 1952). The local population had to work for the haciendas and had limited access to land to sustain their own minimal needs for food. This situation only changed as recently as 1969 when the leftwing military government of Juan Francisco Velasco Alvarado initiated a national agrarian reform program converting the haciendas into state run cooperatives (Guillet, 1974, 1979; Long and Roberts, 1979; Piel, 1995). Most of the cooperatives disintegrated during the 1980´s leading to the redistribution of land to farmer communities in Huancavelica. The process of regained autonomy of farmer communities over their territory coincided with an upsurge in rural violence when the Shining Path (*Sendero Luminoso*), a Maoist inspired guerilla movement, largely took control of the department of Huancavelica (Stern, 1998). Between 1981 and 1992 Huancavelica was closed off from the outside world. Being declared an emergency zone, its largely indigenous population was subject to human rights violations from both the Peruvian army and the Shining Path resulting in the death and displacement of thousands of people (CVR, 2003; Scott Palmer, 1994). Only since 1995 has relative calm returned to Huancavelica´s countryside.

1.5.2 Present situation

Huancavelica is one of Peru's 24 departments and is located in the central Andes surrounded by the departments of Ayacucho (south), Ica (west), Lima (north-west) and Junín (north, north-east). Politically the department is subdivided into 7 provinces, 94 districts and over 500 farmer communities. The department covers an area of 22,131 km², representing 6.1% of the total land area covered by the Peruvian Andes. Huancavelica is inhabited by 447,055 inhabitants; this represents an overall population density of 20.2 persons per km² (INEI, 2005). About 80% of Huancavelica's territory is located between 3,000 and 4,500 m above sea level and 73.9% of its population lives in the countryside (Rubina and Barreda, 2000). Poverty rates in Huancavelica are the highest in Peru (Luna Amancio, 2008; MEF, 2001). In 2001, 74.4% of the total population was considered to be extremely poor (INEI, 2002). Chronic malnutrition (stunting) affects more than 50% of children under 5 years of age while acute malnutrition affects slightly less than 1% (INEI, 1996, 2000).

A total of 86,003 individual farm units in Huancavelica depend on agriculture as its main economic activity (Rubina and Barreda, 2000). Smallholder farming systems in the department are typically mixed, integrating both livestock and crop husbandry (Ossio and Medina, 1985). Most communities maintain communal landholdings for cropping or as pasture land. Average land holdings fluctuate between 0.5 and 3.5 hectares per household (Alfaro *et al.*, 1997). Potato is the principal crop and annually occupies approximately 27% of the total cultivated area followed in importance by barley, wheat, maize, fababeans and peas (Rubina and Barreda, 2000). Mixed livestock populations kept by smallholder farmers in Huancavelica include alpacas, lamas, guinea pigs, cows, sheep and pigs.

1.5.3 Research communities

Field research was conducted in 8 farmer communities following a north-south transect through the department of Huancavelica and covering 4 out of its 7 provinces (table 1.1; fig. 1.1). Communities were selected on the basis of distribution and distance along the north-south transect, tradition of potato cultivation, ethnicity, and relative distance from major markets or cities. Four centers of two communities each represent modestly contrasting research areas. All communities are organized as semi-autonomous indigenous *comunidades campesinas* managed by a locally elected president and at the same time part of municipalities corresponding to the main official geopolitical structure.

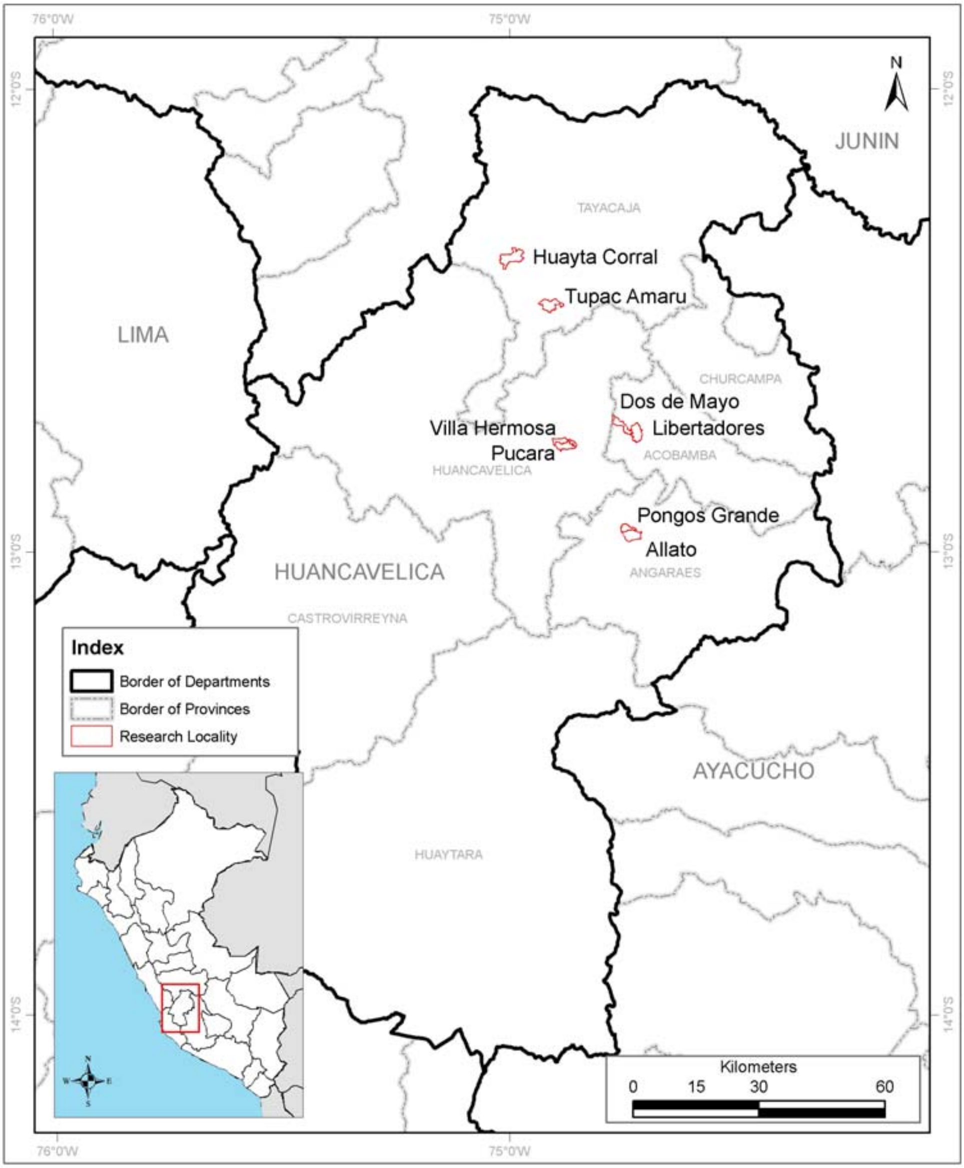
Table 1.1: Basic characteristics of the research communities (Huancavelica, Peru; north-south transect)

Community	Province	District	Transect	Altitude Range (meters above sea level)	No. of Households[1]	Average Household Size[2] (n=319)
Tupac Amaru	Tayacaja	Ahuaycha	North	3,500–4,300	46	5.7
Huayta Corral	Tayacaja	Acraquia	North	3,850–4,500	56	5.0
Villa Hermosa	Huancavelica	Yauli	Central	3,500–4,500	70	5.4
Pucara	Huancavelica	Yauli	Central	3,500–4,500	60	4.4
Dos de Mayo	Huancavelica	Yauli	Central	3,800–4,400	24	5.7
Libertadores	Acobamba	Paucará	Southeast	3,700–4,400	55	5.3
Allato	Angaraes	Lircay	South	3,500–4,200	148	4.1
Pongos Grande	Angaraes	Ccochaccasa	South	3,600–4,300	34	5.0

Sources: [1]Poverty study (2005) and community registers; [2]Base line study (2003/2004)

The communities of Tupac Amaru and Huayta Corral are located closest to the city of Huancayo (department of Junín; 350,000 inhabitants) where large volumes of potatoes are traded at the wholesale market to supply Lima. Both communities interact frequently with this major urban market. The communities of Villa Hermosa and Pucara are located close to the town of Huancavelica (40,000 inhabitants) and regionally recognized for the numerous native potato cultivars grown by its farmers. Both communities interact regularly with the medium-size urban markets of the town of Huancavelica. Dos de Mayo and Libertadores are part of the Chopcca region and ethnic group with the same name. The Chopcca region harbors 16 farmer communities. Interaction with the market mainly occurs at the rural weekend markets of Paucará and Yauli. The Chopcca region is characterized by a particularly strong indigenous identity and organization. Allato and Pongos Grande are located close to the small town of Lircay (capital of the Angaraes province; 3,000 inhabitants). Pongos is regionally recognized as a source of high quality native cultivars which are predominantly offered for sale in Lircay and the mining center of Ccochaccasa.

Figure 1.1: Location of the communities where research was conducted



1.6 The potato crop

The department of Huancavelica is a major center of diversity of the cultivated potato with all cultivated species, except *Solanum ajanhuiri*, reported within its territory (Ochoa, 1999, 2003; Hawkes, 1988, 1990, 1992; Ugent, 1970). Huancavelica has been reported to be a "hotspot" of cultivar diversity (Huamán, 2002; Torres, 2001), yet no systematic inventories of the department's infraspecific diversity exist. Between 1990 and 1998 the annual average potato cropping area in Huancavelica covered 11,681 ha, representing 4.5% of Peru's total annual potato cropping area of approximately 260,000 ha (Egúsquiza, 2000). Average yields fluctuated between 7.7 and 8.6 tons per hectare for this same period (OIA-MINAG, 1998).

The presence of at least 7 wild potato species has been reported in Huancavelica, including *Solanum acaule*, *S. amayanum*, *S. bill-hookeri*, *S. bukasovii*, *S. gracilifrons*, *S. medians* and *S. huancavelicae* (Fuentealba, 2004; Ochoa, 2003; Salas, pers. comm.; Spooner *et al.*, 1999). *S. acaule* and *S. bukasovii* are widely distributed throughout the department while the other species are characterized by more restricted geographical distribution patterns (Hijmans *et al.*, 2002).

1.7 The people

The department of Huancavelica is ethnically Quechua. Quechua Indians (3,200,000 persons) are the largest and most widely distributed indigenous group living in the Peruvian Andes followed by the Aymara (441,743 persons; southern Peru) and Jacaru indigenous peoples (700 persons; central-western Peru; Chirinos, 2001). Quechua was the official language of the Incas (Salomon and Schwartz, 2000). An average of 67% of Huancavelica's population has the Quechua language as its mother tongue (Rubina and Barreda, 2000). Many male Quechua speakers are bilingual managing Spanish as a second language while female Quechua speakers are predominantly monolingual.

Quechua indigenous identity in Huancavelica is strong and expressed through a variety of cultural particulars, including language, communal organization and typical dress (Marroquín, 1968). As a consequence of various centuries of oppression Huancavelica's Quechua population is generally wary towards outsiders. Social inequality is still widespread in Peru's society and Quechua Indians in Huancavelica are among the poorest of Peru's population (MEF, 2001; Rubina and Barreda, 2000). As direct descendants of the people who domesticated and diversified the potato crop they maintain a vibrant culture surrounding the potato crop.

1.8 Organization of the thesis

Chapter 2 provides a systematic inventory of potato genetic diversity. The species and infraspecific diversity of the potato in Huancavelica is characterized and quantified at different scales of conservation: farmer family, community, geographically distanced, regional, *in-* and *ex-situ* subpopulations. The levels of morphological and molecular diversity found within and between different populations are compared. The chapter compares systems of characterization (morphological versus molecular) and reflects upon differences between *in-* and *ex-situ* collections (genetic erosion, genotypes).

Chapter 3 explores three subsystems of the indigenous biosystematics of the potato: folk taxonomy, descriptors and nomenclature. An extensive literature review of indigenous biosystematics is provided. The predominant system of folk taxonomy (ranks and taxa) is described while selected folk specific and varietal taxa (cultivar groups and cultivars) are compared with formal systems of classification (morphological and molecular). The use of folk descriptors by farmers for the identification of cultivars is investigated at the level of flowering plants (aboveground plant parts) and tubers (belowground plant parts). Additionally, the system of cultivar nomenclature is explored for consistency and its basic ethnolinguistic structure.

The annual spatial management of potato diversity is presented in **chapter 4.** Cropping and labor calendars are described and compared taking into account the three different footplough-based tillage systems commonly used for potato cropping after periods of prolonged fallow. The relation between annual field scattering practices and the employment of different cultivar mixtures is investigated. Further, the common notion of microhabitat adaptation of diverse native cultivars as an important factor underlying farmer-driven *in-situ* conservation is explored.

Chapter 5 investigates three specific dimensions of land use in order to gain insights into possible contemporary changes affecting the *in-situ* conservation of potato genetic resources: land use tendencies, rotation designs and their intensity, and sectoral fallow systems. Temporal and spatial (re)arrangements of cropping areas, including the area dedicated to particular crop species and potato cultivar categories, is explored for an 11-year timeframe (1995-2005) taking into the importance of altitudinal ranges inherent to highland agriculture. Predominant rotation designs and rotation intensities (fallowing rates) are compared by cultivar category, altitudinal range and research community (1995-2005). Additionally, the evolution and dynamics of sectoral fallow systems (potato diversity "hotspots") are compared over a 30-year period (1975-2005).

Selected components of farmer seed systems and potato infraspecific diversity are described in **chapter 6**. The internal organization of seed stores and its relation to the overall management of cultivar diversity is described. Seed health, with particular emphasis on virus infection rates, of seed tubers of diverse native cultivars is researched and discussed. The chapter simultaneously investigates seed exchange (provision and acquisition) of native cultivars and zooms in on the particular role of regular markets and biodiversity seed fairs. A special case of seed procurement after severe seed stress caused by out-off-season frost is explored.

Chapter 7 describes the role of biodiverse potatoes within the human diet of households in Huancavelica. Results of analysis of the nutrient content of commonly consumed native-floury (fresh versus boiled) and native-bitter (unprocessed boiled versus freeze-dried boiled) cultivars are presented. The influence of traditional storage on the nutritional composition of selected native-floury cultivars is described. The role of the potato and 3 cultivar categories within the human diet of children and women of fertile age is explored for 2 contrasting periods: food abundance versus scarcity. Further, selected cultural connotations related to the consumption of diverse rather than single cultivars are described.

Finally, **chapter 8** highlights the main findings of the thesis research and discusses implications for externally driven R&D-oriented *in-situ* conservation. Additionally areas of future research are suggested.

2. Species, morphological and molecular diversity of Andean potatoes in Huancavelica, central Peru

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Abstract

Botanical species and infraspecific morphological and molecular diversity represent different yet linked units of conservation. These units were used as the basis for the characterization and quantification of potato diversity at different scales of conservation: farmer family, community, geographically distanced, regional, *in-situ* and *ex-situ* subpopulations. Different methods and tools were combined for the characterization of native cultivars collected in the department of Huancavelica (Peru), including ploidy counts, morphological keys for species identification, morphological descriptor lists and genetic fingerprinting with microsatellite markers (SSR). Datasets were used for descriptive statistics, (dis)similarity analysis, dendrogram construction, cophenetic analysis, matrix correlations calculations (Mantel tests), and Analysis of Molecular Variance (AMOVA).

Farmers in Huancavelica maintain high levels of species, morphological and molecular diversity. All cultivated potato species with the exception of *S. phureja* and *S. ajanhuiri* proved to be present. Tetraploid species were most abundant followed by diploids, triploids and pentaploids. Morphological characterization of 2,481 accessions belonging to 38 *in-situ* collections resulted in the identification of 557 morphologically unique cultivars. Genetic fingerprinting of 989 accessions belonging to 8 *in-situ* collections maintained by farmer families resulted in the identification of 406 genetically unique cultivars. The principal source of molecular variation is found within rather than between geographically distanced and farmer family subpopulations. The regional *in-situ* and a geographically restricted subset of CIP´s core *ex-situ* population share 98.84% of allelic diversity. Yet, *in-situ* collections contain numerous unique genotypes.

2.1 Introduction

2.1.1 Diversity in the field

The contemporary species, morphological or genetic make-up of *in-situ* populations of native potato cultivars in centers of diversity has only been systematically documented in few cases. Research on the structure and levels of variability in a potato's center of origin and diversity is important as it provides a base line for future comparison and has the potential to provide a better understanding of the units (alleles, cultivars, species) and scales (farmer family, geographically distanced, overall regional, and *ex-situ* versus *in-situ* populations) of conservation.

Farmers in the central and southern Peruvian Andes maintain considerable levels of infraspecific diversity within their potato crop because of the intrinsic and multiple functions this diversity provides for their livelihoods (Brush, 2004). The department of Huancavelica is a center of genetic diversity of potato (CIP, 2006; Huamán, 2002; Torres, 2001), yet no systematic inventories of potato diversity have been made as a consequence of the regions' relative isolation and past political instability. Huancavelica is located within the geographical distribution area of all cultivated potato species, with the exception of *Solanum ajanhuiri* (Ochoa 1999, 2003; Hawkes, 1988, 1990, 1992; Ugent, 1970).

2.1.2 Cultivated potato species

Diversity of the cultivated potato in the Andes is characterized by high levels of polymorphism, polyploidy and disputed taxonomic treatments (Hawkes, 1979; Huamán and Spooner, 2002; Spooner *et al.*, 2007). In this article, for practical reasons, we use the classification of Ochoa (1990, 1999) for the cultivated potato as commonly applied in CIP's genebank (CIP, 2006; table 2.1). Yet, it is recognized that this classification of species needs re-evaluation (Spooner *et al.*, 2007).

Table 2.1: Cultivated potato species and taxonomical equivalents

Ploidy	Ochoa (1990, 1999)	Hawkes (1990)	Huamán and Spooner (2002)	Spooner *et al.* (2007)
$2n=2x=24$	*S. goniocalyx*	*S. stenotomum*	*S. tuberosum* Stenotomum Group	*S. tuberosum* diploid Andigenum Group
	S. stenotomum	*S. stenotomum*	*S. tuberosum* Stenotomum Group	*S. tuberosum* diploid Andigenum Group
	S. phureja	*S. phureja*	*S. tuberosum* Phureja Group	*S. tuberosum* diploid Andigenum Group
	S. ajanhuiri	*S. ajanhuiri*	*S. tuberosum* Ajanhuiri Group	*S. ajanhuiri*
$2n=3x=36$	*S. chaucha*	*S. chaucha*	*S. tuberosum* Chaucha Group	*S. tuberosum* triploid Andigenum Group
	S. juzepczukii	*S. juzepczukii*	*S. tuberosum* Juzepczukii Group	*S. juzepczukii*
$2n=4x=48$	*S. tuberosum* subsp. *andigena*	*S. tuberosum* subsp. *andigenum*	*S. tuberosum* Andigenum Group	*S. tuberosum* tetraploid Andigenum Group
	S. tuberosum subsp. *tuberosum*	*S. tuberosum* subsp. *tuberosum*	*S. tuberosum* Chilotanum Group	*S. tuberosum* tetraploid Chilotanum Group
$2n=5x=60$	*S. curtilobum*	*S. curtilobum*	Curtilobum Group	*S. curtilobum*

Since Bukasov (1939) first counted chromosomes of cultivated potatoes, ploidy levels became an important criterion for potato taxonomists to differentiate and identify cultivated species. Ploidy in combination with taxonomical keys can be used to identify cultivated potato species (Huamán, 1983). Andean farmers commonly install four kinds of field plantings: a. single stands of improved cultivars, b. single stands of commercial native-floury cultivars, c. single or mixed stands of native-bitter cultivars for freeze-drying, d. completely mixed stands of native-floury cultivars commonly referred to as *"chaqru*[1] *"* in the Quechua language (Brush *et al.*, 1995). The latter two, c and d, often contain various species with different ploidy levels (Brush, 2004; Jackson *et al.*, 1980).

2.1.3 Characterization of infraspecific diversity

Descriptors lists of the cultivated potato have continuously been improved and are designed for the comparison of morphological variability within and among potato cultivar populations (Gomez, 2000; Huamán *et al.*, 1977; Huamán and Gomez, 1994; Soukup, 1939). While morphological descriptors are still commonly used as an inexpensive and accessible tool for germplasm characterization, they have been shown to overlap extensively across cultivated species and are nowadays increasingly complemented with molecular markers (Huamán and Spooner, 2002; Celebi-Toprak et al., 2005). A major advantage of molecular markers is that they are environmentally neutral and independent, and therefore more robust and unbiased compared to morphological descriptors. Simple Sequence Repeats (SSR; microsatellites) have been identified and applied at CIP because of their high genetic information content, high reproducibility, and simplicity of use (Ghislain *et al.*, 2004). A comparison between morphological descriptors and molecular markers, when applied to large native cultivar collections, has the potential to reveal possible complementarities or contrasts between both systems of characterization.

2.1.4 *In-situ* and *ex-situ* populations

In-situ conservation of crop genetic resources is recognized as an important complementary strategy to *ex-situ* conservation efforts (Bellon, 2004; Brush, 2000; Maxted *et al.*, 1997, 2002), partially because of the ongoing evolution of genetic diversity under farmer selection. Dynamic temporal changes in the species, morphological, and molecular diversity of geographically defined (sub)populations of potato cultivars can come about through mutations, gene flow, varietal turnover, genetic erosion or cultivar loss, and extra-regional seed exchange (Auroi, 1985; Celis *et al.*, 2004; Zimmerer, 2003). Core *ex-situ* collections ideally represent most of the diversity in the reserve collection and thus allow one to extrapolate conclusions to the entire *ex-situ* collection or defined *in-situ* populations (Huamán et al., 2000; Tohme et al., 1996). Yet, *ex-* and *in-situ* populations of potato cultivars from the same geographical origin and collected at different moments have never before been compared. Little direct evidence is available on how genebank germplasm differs from that under contemporary farmer conservation (Bamberg and Del Rio, 2005).

2.1.5 Objectives

The objectives of this article are: a. to quantify and describe the levels of species, morphological, and molecular diversity of *in-situ* populations of native potato cultivars as maintained in the department of Huancavelica (Peru) at multiple scales: farmer family, community, geographically distanced, and/or overall regional populations, b. to compare systems of classification based on the use of CIP's morphological descriptor list and the use of 18 polymorphic Single Sequence Repeat (SSR) markers for a large population of native potato cultivars from Huancavelica, c. to

[1] The term "*chaqru*" (complete cultivar mixtures) is used throughout this thesis and refers to mixtures of native cultivars which are generally randomly planted within farmers fields. So-called "*chaqru*" fields may contain 2 up to over 50 native cultivars. Farmers also use the term to refer to complete cultivar mixtures for consumption or in storage.

compare the total *in-situ* population of native cultivars maintained by farmers in Huancavelica against a geographically restricted subset of accessions from CIP's core *ex-situ* population as maintained in the genebank.

2.2 Materials and methods

2.2.1 *In-situ* collections for characterization

Eight communities following a north-south transect through the department of Huancavelica were selected on the basis of distribution and distance along the transect, tradition of potato cultivation, ethnicity, and relative distance from major markets or cities (see chapter 1). During three subsequent agricultural seasons, farmer and communal potato collections of native potato cultivars were characterized using different tools: ploidy counts, morphological descriptor lists and molecular markers. Families or communal groups with appreciable diversity were identified and seed-tubers of each farmer-recognized cultivar stored in net-bags. Some farmer families maintained very large cultivar collections and subsets of their total collection were installed in subsequent agricultural seasons. Accessions were labeled and on-farm trials with a minimum of five and a maximum of ten plants per accession installed. Field space was provided by the participating families or groups with prior informed consent and with authorization obtained during communal assemblies. The *in-situ* collections were used as the basis for ploidy counts, botanical species identification, morphological and molecular (SSR) characterization (table 2.2). Additionally, two collection trips were undertaken in 2005 to search for *Solanum phureja* in inter-Andean valleys below 3,400 m altitude. One trip was undertaken to the remote eastern districts of Huachocolpa and Tintay Puncu (Tayacaja province) and one to the low inter-Andean valley of Lircay following the Totora watershed (Angaraes province).

2.2.2 Ploidy counts and species identification

Ploidy levels in combination with morphological keys were used to determine the botanical species to which accessions belonged. Species identification was double checked in open field and under greenhouse conditions using the botanical keys developed by Huamán (1983). Ploidy was determined by both microscopy and flow cytometry. The microscopy method followed standard procedures (Chen and Hai, 2005; Watanabe and Orrillo, 1993): a. collection of 0.5-1.0 cm long root tips between 11:20 and 12:00 a.m., b. treatment of root tips with a solution of Ambush 50EC for the detention of mitosis in metaphase (incubate root tips in solution with 15 µl stock of Ambush 50EC in 100 ml H_2O pH 5.8 for 24 hours at 4ºC; wash 15 minutes with H_2O pH 5.8), c. optional fixation (incubate in 3 parts ethanol 96% and 1 part acetic acid at 20ºC for 24 hours; rinse with ethanol 70% and air dry; store at 4ºC for not longer than 7-10 days), d. hydrolysis (incubate in 1N HCl at 60ºC for 8-10 minutes, wash for 15 minutes with distilled water), e. staining (incubate in lacto-propionic orcein for 3 minutes), f. preparation of squash slides, g. microscopy (actual counting). Flow cytometry was conducted with a Partec® ploidy analyzer through measurement of the total DNA content of nuclei from leaf samples. Ploidy levels were read from real time DNA histograms.

2.2.3 Morphological characterization

The morphological diversity of native cultivar collections was characterized using CIP's formal descriptor list and color card (Gómez, 2000; Huamán and Gómez, 1994). This formal list consists of 17 morphological descriptors with a total of 32 morphological character states, 18 of which are considered to be environmentally stable (appendix I). Similarity analysis, dendrogram construction, cophenetic analysis and matrix correlations calculations (Mantel tests) were conducted. A standardized similarity analysis with an average taxonomic distance coefficient

Table 2.2: Potato cultivar collections installed in on-farm trials and characterized (2003-2006)

In-situ collect. number	Season	Farmer / group	Community	Accessions originally installed	Accessions with chromosome counts	Accessions with species identification	Accessions morphologically characterized[a]	Accessions molecularly characterized
ISC-1	2003-2004	Antonio Paytan Ccantu	Pucara	171	171	168	164	175
ISC-2	2003-2004	Armando Ramos Cóndor	Villa Hermosa	154	95	69	117	160
ISC-3	2003-2004	Isaac Ramos Cóndor	Villa Hermosa	147	108	86	81	138
ISC-4	2003-2004	Juan Ramos Cóndor	Villa Hermosa	156	121	99	104	161
ISC-5	2003-2004	Juana Segama Velito	Allato	193	187	158	193	170
ISC-6	2003-2004	Teresa Martínez Velito	Allato	58	57	49	58	58
ISC-7	2003-2004	Quintin Velazquez Huamani	Pongos Grande	73	70	62	69	70
ISC-8	2003-2004	Eulogio Raymuno Escobar	Libertadores	55	54	51	46	57
ISC-9	2003-2004	Communal Group	Dos de Mayo	90	33	30	33	0
ISC-10	2004-2005	Alejandro Huamán Matamoros	Villa Hermosa	97	92	92	93	0
ISC-11	2004-2005	Antonio Paytan Ccantu	Pucara	89	89	89	87	0
ISC-12	2004-2005	Armando Paytan Condori	Pucara	79	78	78	71	0
ISC-13	2004-2005	Armando Ramos Cóndor	Villa Hermosa	100	98	98	74	0
ISC-14	2004-2005	Cesario Escobar Ramos	Pongos Grande	33	33	33	31	0
ISC-15	2004-2005	Communal Group 1	Huayta Corral	32	22	22	13	0
ISC-16	2004-2005	Communal Group 2	Huayta Corral	72	72	72	47	0
ISC-17	2004-2005	Dionisio Huamán Méndez	Tupac Amaru	28	25	25	14	0
ISC-18	2004-2005	Eulogio Raymuno Escobar	Libertadores	43	43	43	43	0
ISC-19	2004-2005	Freddy Huatarunco Rojas	Tupac Amaru	39	37	37	39	0
ISC-20	2004-2005	José Cahuana Escobar	Dos de mayo	59	59	59	59	0
ISC-21	2004-2005	Juan Ramos Cóndor	Villa Hermosa	172	163	162	119	0
ISC-22	2004-2005	Juana Segama Velito	Allato	55	55	55	50	0
ISC-23	2004-2005	Leoncio Quinto Escobar	Dos de Mayo	99	98	97	89	0
ISC-24	2004-2005	Pablo Raymundo Escobar	Libertadores	67	67	67	65	0
ISC-25	2004-2005	Pedro Montes Velazquez	Pongos Grande	37	37	37	35	0
ISC-26	2004-2005	Pío Velazquez Huamani	Pongos Grande	103	100	100	93	0
ISC-27	2004-2005	Saturnino Janampa Rua	Allato	50	50	50	49	0
ISC-28	2004-2005	Teresa Martínez Velito	Allato	51	51	51	46	0
ISC-29	2004-2005	Ubaldo Cano Cahuana	Huayta Corral	23	23	23	13	0
ISC-30	2004-2005	Victor Palomino Matamoros	Dos de Mayo	87	35	35	29	0

ISC-31	2005-2006	Cirilo Rojas	Tupac Amaru	60	0	0	44	0
ISC-32	2005-2006	Communal Group	Huayta Corral	73	0	0	46	0
ISC-33	2005-2006	Dionisio Huamán Méndez	Tupac Amaru	28	0	0	25	0
ISC-34	2005-2006	Francisco Pérez	Tupac Amaru	52	0	0	42	0
ISC-35	2005-2006	Freddy Huatarunco Rojas	Tupac Amaru	95	0	0	79	0
ISC-36	2005-2006	José Cahuana Escobar	Dos de Mayo	107	0	0	100	0
ISC-37	2005-2006	Leoncio Quinto Escobar	Dos de Mayo	120	0	0	94	0
ISC-38	2005-2006	Ubaldo Cano Cahuana	Huayta Corral	41	0	0	27	0

[a] = accessions morphologically characterized with > 12.5% of missing data are not considered

(DIST), Sequential Agglomerative Hierarchal Nested (SAHN) cluster analysis, and Unweighted Pair Group Method Arithmetic Average (UPGMA) clustering method, using the total set of descriptors, was carried out for farmer family (38), community (8) and overall regional (sub)populations (1) using NTSYS-pc 2.1 software. Only accessions with less than 12.5% of missing data were included in the analysis using the total set of descriptors. Additionally, combined community and overall regional (sub)population datasets were submitted to the same analysis using only environmentally stable descriptors. Ploidy data was used in the analysis when available.

2.2.4 Molecular characterization

An initial population consisting of 1007 accessions, belonging to 8 farmer families, was molecularly characterized using Single Sequence Repeat (SSR; microsatellite) markers (tables 2.2 and 2.3). Standard procedures as practiced at CIP were applied, including DNA extraction with DNeasy 96 plant kits, high throughput genotyping with a LI-COR 4300 DNA Analysis System, and SSR allele scoring with SAGA Generation 2 software (LI-COR). 18 highly polymorphic microsatellite markers (SSR) were used for genetic fingerprinting (Feingold et al., 2005; Ghislain et al., 2004; Milbourne et al., 1998; Núñez et al., 2005). These were chosen to cover the whole genome with a range of 6 to 17 alleles per SSR loci (average 10) and a PIC (Polymorphism Index Content[2]) in the range of 0.585 to 0.832 (average 0.724). A total of 989 accessions had good quality data (< 0.3% of missing data) and were used for further data analysis.

Standardized dissimilarity analysis for farmer family (8), geographically distanced (2) and overall regional (sub)populations (1) were conducted using the Jaccard coefficient and UPGMA clustering method applying NTSYS-pc 2.1 software. Dissimilarity trees (dendrograms) were built with the same data using an Unweighted Neighbor Joining (NJ) clustering method for a dissimilarity matrix calculated with the Jaccard's coefficient using DARwin 4.0[3] and NTSYS-pc 2.1 software. PIC values were calculated for all (sub)populations and SSR markers. Additionally, relative allele frequencies for the total regional population and the defined subpopulation were calculated. The population genetic structures of the geographically distanced and farmer family subpopulations were compared among and between each other using Analysis of Molecular Variance (AMOVA) with Arlequin 3.11 software[4] (Excoffier et al., 1992).

[2] The Polymorphism Index Content (PIC) was calculated with Nei's statistic (Nei, 1973, 1987): $PIC=1-\sum(p_i^2)$, where "p_i" is the frequency of the i-th allele detected in all individuals of the population.

[3] CIRAD-FLHOR, DARwin for windows version 4.0, Équipe de Mathématiques et Informatique Appliqées, 34398 Montpellier, Cedex 5, France, 2003.

[4] Stefan Schneider, David Roessli, and Laurent Excoffier (2000), Arlequin ver. 3.11: a software for population genetics and data analysis. Genetics and Biometry Laboratory, University of Geneva, Switzerland.

Table 2.3: Summary of SSR marker coverage: number of alleles, range of alleles, and Polymorphic Information Content (PIC)

SSR Name	Source of markers (*)	Number of Alleles	Range Length of Alleles (bp)	PIC	Map Location (chromosome)
STM0019a	SCRI	17	159– 213	0.754	VI
STM0019b	SCRI	11	93–116	0.585	-
STGBSS	SCRI	10	140–157	0.812	VIII
STM0037	SCRI	11	89–133	0.720	XI
STM0031	SCRI	8	185–211	0.698	VII
STM1052	SCRI	7	226–263	0.781	IX
STM1106	SCRI	10	130–196	0.800	X
STM5127	SCRI	13	248–291	0.832	I
STG0006	TIGR	8	148–178	0.610	II
STG0010	TIGR	7	176–186	0.627	II
STG0020	TIGR	13	139–169	0.799	IV
STI0003	IDAHO	11	149–188	0.673	VIII
STI0014	IDAHO	7	136–154	0.686	IX
STI0022	IDAHO	6	131–151	0.664	VIII
STI0023	IDAHO	14	172–230	0.723	X
STI0030	IDAHO	9	104–125	0.800	XII
STI0032	IDAHO	10	127–148	0.716	V
STI0036	IDAHO	11	133–164	0.747	-

Source: Ghislain *et al.*, 2004; * SCRI (Scottish Crop Research Institute; Dundee, Scotland, UK), TIGR (The Institute of Genomic Research; Rockville, USA), IDAHO (University of Idaho; Moscow, USA)

2.2.5 Comparison of morphological and molecular analysis

A subset of 679 accessions with both complete morphological descriptor and SSR marker data were used to compare both systems of characterization. (Dis)similarity analyses using an average taxonomic distance coefficient (DIST) for morphological data and the Jaccard similarity coefficient for molecular data were conducted. An UPGMA clustering method was used for both datasets. Dendrograms were constructed and Mantel tests, using both similarity and cophenetic matrixes, conducted with NTSYS-pc 2.1 software. Matrix correlation values (R) were calculated for all (sub)populations comparing: a. similarity matrixes constructed with morphological versus molecular (SSR) data, b. cophenetic matrixes with morphological versus molecular (SSR) data, c. similarity versus cophenetic matrixes for morphological data, d. similarity versus cophenetic matrixes for SSR marker data.

2.2.6 Comparison of the *in-situ* and *ex-situ* collection

The total fingerprinted *in-situ* population (n=989) was compared with CIP's *ex-situ* core collection (n=172) from central Peru. The latter was selected on the basis of geographical origin including all accessions from Huancavelica and the direct adjunct departments of Junin, Ayacucho and Lima. Both datasets were compared using the same set of 18 SSR markers. Both datasets were used to build a dissimilarity tree with an Unweighted Neighbor Joining (NJ) clustering method (Jaccard's coefficient) and to conduct Principal Components Analysis (PCA) using DARwin 4.0 software. The population genetic structures of the *in-situ* and geographically delimited *ex-situ* core populations were compared applying AMOVA with Arlequin 3.11 software.

2.3 Results

2.3.1 Species diversity of *in-situ* collections

The ploidy level and species identification of a total of 2,223 and 2,097 accessions respectively was established. Resulting distribution patterns are presented at three scales: a. farmer family subpopulations, b. farmer community subpopulations, c. overall regional population. The first considers 30 farmer family subpopulations (ISC-1 till ISC-30). The second considers 8 subpopulations based on geopolitical boundaries of the communities. The third considers a single population with all accessions.

Tetraploids were most abundant followed by diploids, triploids and pentaploids (table 2.4 / fig. 2.1). All 30 farmer family collections contained diploids, triploids and tetraploids while only 14 collections contained pentaploids. Notable differences between some of the communities exist concerning their ploidy distribution pattern (fig. 2.1). Diploids were more abundant in northern Huancavelica (Tupac Amaru and Huayta Corral) while tetraploids were more abundant in central-eastern Huancavelica (Libertadores and Dos de Mayo). No pentaploids were found in the communities of Allato and Pongos Grande.

Table 2.4: Ploidy distribution of the *in-situ* collections (2003-04 / 2004-05) for farmer family subpopulations and the overall regional population

***In-situ* collection number (*)**	**N**	**Undetermined**	**Ploidy Distribution (%)**			
			Diploids 2*n*=2*x*=24	**Triploids 2*n*=3*x*=36**	**Tetraploids 2*n*=4*x*=48**	**Pentaploids 2*n*=5*x*=60**
ISC-1	171	0.0	38.0	17.0	44.4	0.6
ISC-2	154	38.3	22.7	11.7	27.3	0.0
ISC-3	147	26.5	21.1	15.6	36.7	0.0
ISC-4	156	22.4	20.5	23.7	33.3	0.0
ISC-5	193	3.1	23.8	13.5	59.6	0.0
ISC-6	58	1.7	53.4	20.7	24.1	0.0
ISC-7	73	4.1	23.3	28.8	43.8	0.0
ISC-8	55	1.8	14.5	10.9	72.7	0.0
ISC-9	90	63.3	6.7	5.6	24.4	0.0
ISC-10	97	5.2	34.0	24.7	35.1	1.0
ISC-11	89	0.0	28.1	28.1	42.7	1.1
ISC-12	79	1.3	25.3	12.7	58.2	2.5
ISC-13	100	2.0	29.0	14.0	53.0	2.0
ISC-14	33	0.0	36.4	15.2	48.5	0.0
ISC-15	32	31.3	34.4	21.9	9.4	3.1
ISC-16	72	0.0	37.5	30.6	30.6	1.4
ISC-17	28	10.7	28.6	46.4	14.3	0.0
ISC-18	43	0.0	25.6	25.6	46.5	2.3
ISC-19	39	5.1	33.3	28.2	30.8	2.6
ISC-20	59	0.0	22.0	18.6	57.6	1.7
ISC-21	172	5.2	31.4	15.7	47.7	0.0
ISC-22	55	0.0	34.5	14.5	50.9	0.0
ISC-23	99	1.0	22.2	27.3	46.5	3.0
ISC-24	67	0.0	19.4	28.4	49.3	3.0
ISC-25	37	0.0	32.4	32.4	35.1	0.0
ISC-26	103	2.9	34.0	31.1	32.0	0.0
ISC-27	50	0.0	22.0	30.0	48.0	0.0
ISC-28	51	0.0	23.5	17.6	58.8	0.0
ISC-29	23	0.0	39.1	21.7	34.8	4.3
ISC-30	87	59.8	5.7	12.6	20.7	1.1
Total	**2,512**	**11.5**	**26.5**	**19.7**	**41.6**	**0.8**

* = ISC-31 till ISC-38 are not included because ploidy counts were not conducted

Figure 2.1: Fully determined ploidy distribution (2003-04 & 2004-05) for farmer community subpopulations and the overall regional population

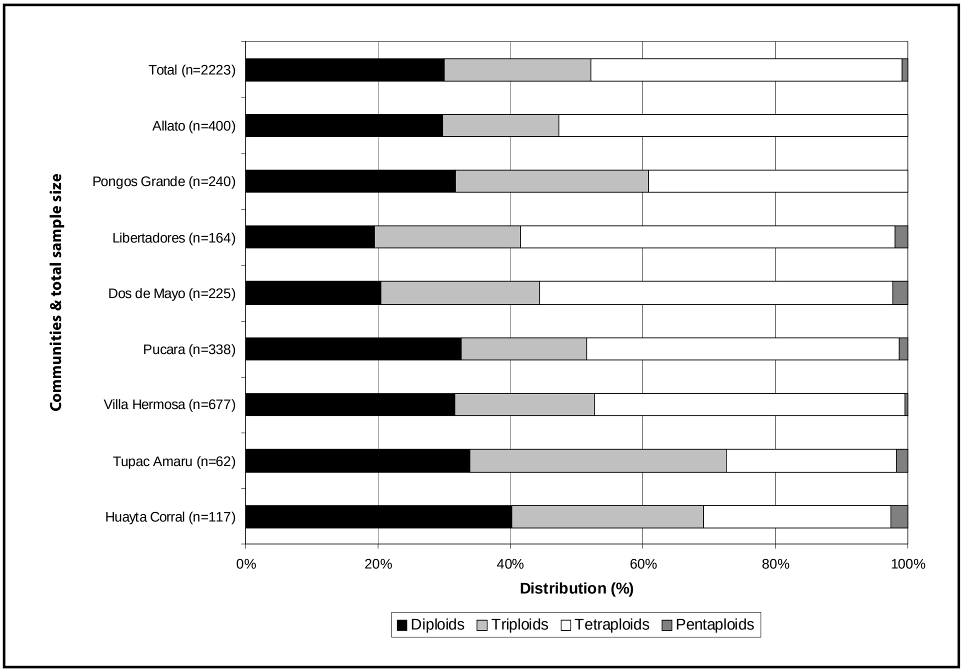


Table 2.5 shows the distribution of cultivated potato species by farmer family subpopulation and for the overall regional population. The distribution pattern of fully determined species by farmer community and overall regional (sub)population provides an interesting overview of their relative infraspecific diversity (fig. 2.2). Regionally, but also at the community level, *S. tuberosum* subsp. *andigena* (49.5%), *S. chaucha* (22.7%) and *S. goniocalyx* (17.7%) are the most abundant in terms of inherent cultivar diversity. The species with least infraspecific diversity are the *S. curtilobum* (0.9%) and *S. juzepczukii* (1.0%). *S. stenotomum* (7.2%) occupies an intermediate position. Some cultivars belonging to *S. tuberosum* subsp. *tuberosum* were encountered representing 1.0% of the total sample with species identification. Mostly these were old improved potato cultivars that farmers had incorporated into their native cultivar stocks.

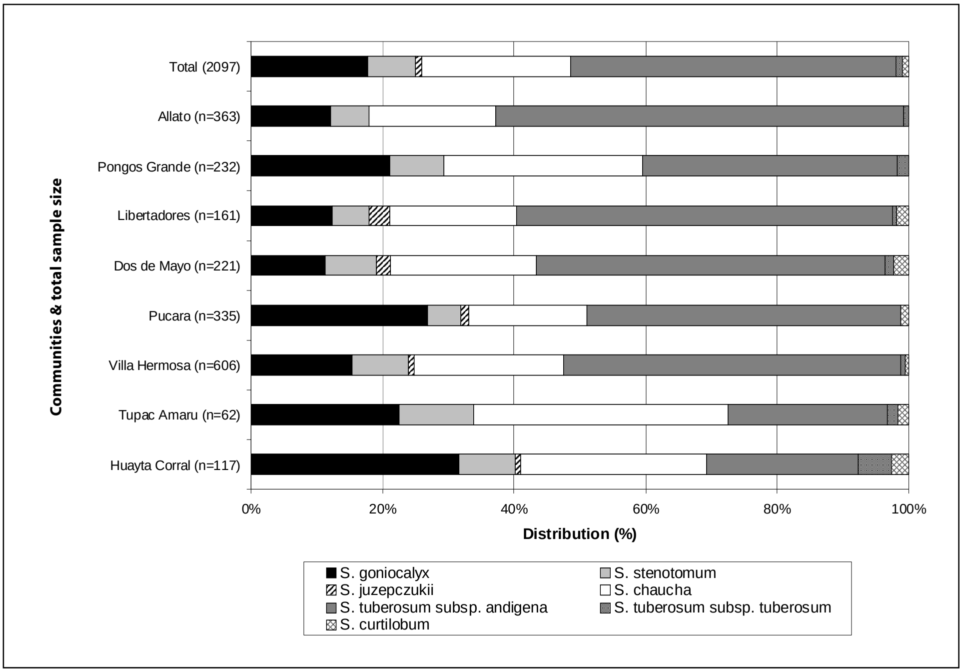
Table 2.5: Species distribution of the *in-situ* collections (2003-04 / 2004-05) for farmer family subpopulations and the overall regional population

***In-situ* collection number (*)**	**N**	**Species Distribution (%)**							
		Undet.	**Gon**	**Stn**	**Juz**	**Cha**	**Adg**	**Tbr**	**Cur**
ISC-1	171	1.8	34.5	1.8	1.2	15.8	44.4	0.0	0.6
ISC-2	154	55.2	3.9	1.9	0.0	11.7	27.3	0.0	0.0
ISC-3	147	41.5	4.8	2.7	0.0	15.6	34.0	1.4	0.0
ISC-4	156	36.5	3.8	2.6	1.3	22.4	33.3	0.0	0.0
ISC-5	193	18.1	8.3	0.5	0.0	13.5	59.1	0.5	0.0
ISC-6	58	15.5	10.3	0.0	0.0	20.7	53.4	0.0	0.0
ISC-7	73	15.1	9.6	2.7	0.0	28.8	39.7	4.1	0.0
ISC-8	55	7.3	5.5	3.6	0.0	10.9	72.7	0.0	0.0
ISC-9	90	66.7	1.1	2.2	0.0	5.6	24.4	0.0	0.0
ISC-10	97	5.2	26.8	7.2	0.0	24.7	33.0	2.1	1.0
ISC-11	89	0.0	20.2	7.9	2.2	25.8	42.7	0.0	1.1
ISC-12	79	1.3	16.5	8.9	0.0	12.7	58.2	0.0	2.5
ISC-13	100	2.0	19.0	10.0	3.0	11.0	53.0	0.0	2.0
ISC-14	33	0.0	27.3	9.1	0.0	15.2	48.5	0.0	0.0
ISC-15	32	31.3	25.0	9.4	0.0	21.9	3.1	6.3	3.1
ISC-16	72	0.0	33.3	4.2	1.4	29.2	30.6	0.0	1.4
ISC-17	28	10.7	25.0	3.6	0.0	46.4	10.7	3.6	0.0
ISC-18	43	0.0	14.0	11.6	4.7	20.9	44.2	2.3	2.3
ISC-19	39	5.1	17.9	15.4	0.0	28.2	30.8	0.0	2.6
ISC-20	59	0.0	16.9	5.1	1.7	16.9	54.2	3.4	1.7
ISC-21	172	5.8	16.9	14.0	0.0	15.7	47.7	0.0	0.0
ISC-22	55	0.0	9.1	25.5	0.0	14.5	49.1	1.8	0.0
ISC-23	99	2.0	12.1	9.1	2.0	25.3	46.5	0.0	3.0
ISC-24	67	0.0	16.4	3.0	4.5	23.9	49.3	0.0	3.0
ISC-25	37	0.0	27.0	5.4	0.0	32.4	32.4	2.7	0.0
ISC-26	103	2.9	22.3	11.7	0.0	31.1	32.0	0.0	0.0
ISC-27	50	0.0	12.0	10.0	0.0	30.0	46.0	2.0	0.0
ISC-28	51	0.0	21.6	2.0	0.0	17.6	58.8	0.0	0.0
ISC-29	23	0.0	21.7	17.4	0.0	21.7	17.4	17.4	4.3
ISC-30	87	59.8	2.3	3.4	2.3	10.3	19.5	1.1	1.1
Total	**2,512**	**16.5**	**14.8**	**6.1**	**0.8**	**18.9**	**41.3**	**0.9**	**0.8**

* Undet = undetermined; Gon = *S. goniocalyx* (2*n*=2*x*=24); Stn = *S. stenotomum* (2*n*=2*x*=24); Juz = *S. juzepczukii* (2*n*=3*x*=36); Cha = *S. chaucha* (2*n*=3*x*=36); Adg = *S. tuberosum* subsp. *andigena* (2*n*=4*x*=48); Tbr = *S. tuberosum* subsp. *tuberosum* (2*n*=4*x*=48), of hybrid origin; Cur = *S. curtilobum* (2*n*=5*x*=60)

S. ajanhuiri was not encountered in Huancavelica; this is in accordance with previous reports from potato collectors. Two collection trips were undertaken in 2005 to search specifically for *S. phureja*, but it was never encountered even though it has been collected in the lower inter-Andean and eastern valleys in the past (Ochoa, 2003, p. 56-57). Older farmer also reported the past presence of *S. phureja*, vernacularly known as "chaucha", in fields below 3,400 m of altitude.

Figure 2.2: Fully determined species distribution (2003-04 & 2004-05) for farmer community subpopulations and the overall regional population



2.3.2 Morphological diversity of *in-situ* collections

Similarity analysis, dendrogram construction, cophenetic analysis and matrix correlations calculations (Mantel tests) were conducted for morphologically characterized populations at the following scales: a. farmer family subpopulations (38), b. community subpopulations (8), c. overall regional population (1). The number of unique cultivars, morphotypes and pure duplicates within morphologically characterized cultivar (sub)populations was established.

Here unique cultivars are defined as accessions with no pairs at < 75.0% similarity for the farmer family (38) and community subpopulations (8); these are represented in each dendrogram by a similarity coefficient higher than the coefficient limit (table 2.6). The total regional population (1) was dissected more rigidly considering accessions as unique cultivars when having no pairs at < 66.7% and < 58.3% similarity (comparison at two defined coefficient limits). Morphotypes are defined as accessions belonging to a cluster at = 75% similarity; these are represented in the dendrogram by a similarity coefficient lower or equal to the coefficient limit. The coefficient limit was calculated at 75% similarity for each dendrogram in order to separate unique cultivars from morphotypes. Pure duplicates are accessions with one or more equal pairs at a coefficient of 0.00 (100% similarity). Accessions considered morphotypes or pure duplicates have one or more pairs with numerous or all morphological character states in common. Only one accession of a subcluster of morphotypes or duplicates represents a unique cultivar.

Results at the scale of farmer family subpopulations show that appreciable morphological diversity exists within potato cultivar pools managed by individual households (table 2.6). These selected and morphologically characterized subpopulations contained a minimum of 13 and a maximum of 160 unique cultivars per subpopulation. No pure duplicates were found within the farmer family subpopulations. Yet, 25 out of a total of 38 morphologically characterized farmer family subpopulations contained between 1 to 33 accessions classified as morphotypes. These results suggest that households in Huancavelica conserve a knowledge system which efficiently allows for the identification of distinct cultivars.

Table 2.6: Results of a similarity analysis[1] for *in-situ* collections (ISC) using the DIST coefficient and UPGMA clustering method applying NTSYS-pc 2.1 software and consequent identification of unique cultivars, morphotypes, and pure duplicates by farmer family subpopulation

Farmer family population	Accessions (n)	Coeff. Range	Coeff. limit	Mantel test[a] (R)	Unique cultivars	Morphotypes	Pure duplicates
ISC-01	164	0.00-1.20	0.30	0.72	150	14	0
ISC-02	117	0.00-1.17	0.29	0.76	108	9	0
ISC-03	81	0.00-1.17	0.29	0.76	78	3	0
ISC-04	104	0.00-1.05	0.26	0.69	102	2	0
ISC-05	193	0.00-1.17	0.29	0.71	160	33	0
ISC-06	58	0.00-1.03	0.26	0.75	55	3	0
ISC-07	69	0.00-1.03	0.26	0.75	68	1	0
ISC-08	46	0.00-1.00	0.25	0.74	46	0	0
ISC-09	33	0.00-1.20	0.30	0.82	29	4	0
ISC-10	93	0.00-1.17	0.29	0.72	90	3	0
ISC-11	87	0.00-1.14	0.28	0.76	80	7	0
ISC-12	71	0.00-1.19	0.30	0.70	70	1	0
ISC-13	74	0.00-1.09	0.27	0.72	73	1	0
ISC-14	31	0.00-1.10	0.28	0.78	30	1	0
ISC-15	13	0.00-1.12	0.28	0.81	13	0	0
ISC-16	47	0.00-1.05	0.26	0.76	47	0	0
ISC-17	14	0.00-0.97	0.24	0.85	13	1	0
ISC-18	43	0.00-1.03	0.26	0.74	41	2	0
ISC-19	39	0.00-1.02	0.26	0.71	39	0	0
ISC-20	59	0.00-1.02	0.26	0.65	57	2	0
ISC-21	119	0.00-1.16	0.29	0.75	114	5	0
ISC-22	50	0.00-1.09	0.27	0.71	50	0	0
ISC-23	89	0.00-1.13	0.28	0.75	85	4	0
ISC-24	65	0.00-1.00	0.25	0.72	65	0	0
ISC-25	35	0.00-1.00	0.25	0.72	35	0	0
ISC-26	93	0.00-1.02	0.26	0.73	87	6	0
ISC-27	49	0.00-1.14	0.28	0.72	47	2	0
ISC-28	46	0.00-1.04	0.26	0.78	43	3	0
ISC-29	13	0.00-1.08	0.27	0.86	13	0	0
ISC-30	29	0.00-1.10	0.28	0.76	29	0	0
ISC-31	44	0.00-1.19	0.30	0.76	44	0	0
ISC-32	46	0.00-1.18	0.30	0.73	46	0	0
ISC-33	25	0.00-0.96	0.24	0.71	25	0	0
ISC-34	42	0.00-1.29	0.32	0.78	42	0	0
ISC-35	79	0.00-1.16	0.29	0.77	75	4	0
ISC-36	100	0.00-1.01	0.25	0.73	95	5	0
ISC-37	94	0.00-1.07	0.27	0.75	94	0	0
ISC-38	27	0.00-1.07	0.27	0.79	26	1	0

[1] analysis based on the use of all character states from the descriptor list including ploidy when available; [a] Mantel test (matrix correlation R) comparing the similarity and cophenetic values

Relatively high numbers of morphotypes were encountered at the level of community subpopulations. The total size of unique cultivar pools differs considerable between the 8 farmer communities (table 2.7). In Villa Hermosa the highest total number of unique cultivars was identified, reaffirming the community's regional reputation as a potato diversity "hotspot". A lower level of total morphological diversity was encountered in Huayta Corral. Yet, this community still harbors at least 127 morphologically distinct cultivars. The total size of community cultivar pools is frequently influenced by a few households maintaining large cultivar pools.

Table 2.7: Results of a similarity analysis[1] for *in-situ* collections (ISC) using the DIST coefficient and UPGMA clustering method applying NTSYS-pc 2.1 software and consequent identification of unique cultivars, morphotypes, and pure duplicates by community subpopulation

Community population	Accessions (n)	Coeff. range	Coeff. limit	Mantel test[a] (R)	Unique cultivars	Morphotypes	Pure duplicates
Huayta Corral	146	0.00-1.13	0.28	0.78	127	19	0
Tupac Amaru	243	0.00-1.12	0.28	0.79	195	48	0
Villa Hermosa	588	0.00-1.15	0.29	0.76	425	163	0
Pucara	322	0.00-1.13	0.28	0.73	258	63	1
Dos de Mayo	404	0.00-1.13	0.28	0.75	320	83	1
Libertadores	154	0.00-1.12	0.28	0.80	128	26	0
Pongos Grande	228	0.00-1.10	0.28	0.81	179	48	1
Allato	396	0.00-1.12	0.28	0.76	272	118	6

[1] analysis based on the use of environmentally stable character states from the descriptor list including ploidy when available;
[a] Mantel test (matrix correlation R) comparing the similarity and cophenetic values

Depending on the defined coefficient limit, 0.38 or 0.48 at 66.7% and 58.3% similarity respectively (coefficient range 0.00-1.15), the total regional population (n=2,481 accessions) consisted of between 764 and 349 unique potato cultivars. The latter (349) is likely to represent an underestimation of the total size of the regional native cultivar pool while the number of 764 unique cultivars might slightly over-represent the total level of diversity. The intermediate value between the two "extremes" establishes 557 as the estimated total number of morphologically distinct and unique cultivars as regionally maintained among the 8 communities. Cophenetic analysis and the comparison of similarly and cophenetic matrices for the total regional population resulted in a matrix correlation value (R) of 0.76, indicating robustness of the dendrogram constructed with descriptor data of 2,481 accessions.

2.3.3 Molecular diversity of *in-situ* collections

Results are presented at three scales: a. farmer family subpopulations (8), b. geographically distanced subpopulations (2), c. overall regional population (1). The first scale considers 8 farmer family collections (ISC-1 to ISC-8). The second scale considers 2 subpopulations based on geographical distance: subpopulation 1 (P1; n=634; ISC-1 to ISC-4) with all accessions belonging to 4 farmer families from the 2 communities of Villa Hermosa and Pucara (central Huancavelica) and subpopulation 2 (P2; n=298; ISC-5 to ISC-7) with all accessions belonging to 3 farmer families from the 2 communities of Pongos Grande and Allato (southern Huancavelica). The third scale considers a single population with all molecularly characterized accessions (8 farmer families from 6 communities; n=989).

Table 2.8 presents the number of unique potato cultivars, morphotypes and pure duplicates encountered for each (sub)population. Unique cultivars are accessions with no pairs at > 25% dissimilarity; these are represented in the dendrogram by a dissimilarity coefficient lower than the coefficient limit (table 2.8). Morphotypes are accessions belonging to a cluster at $\leq$ 25% dissimilarity; these are represented in the dendrogram by a dissimilarity coefficient higher or equal to the coefficient limit. Pure duplicates are accessions with one or more equal pairs at a coefficient of 1.00 (100% similarity).

Table 2.8: Results of a dissimilarity analysis using the Jaccard coefficient and UPGMA clustering method applying NTSYS-pc 2.1 software and consequent identification of unique cultivars, morphotypes, and pure duplicates by population

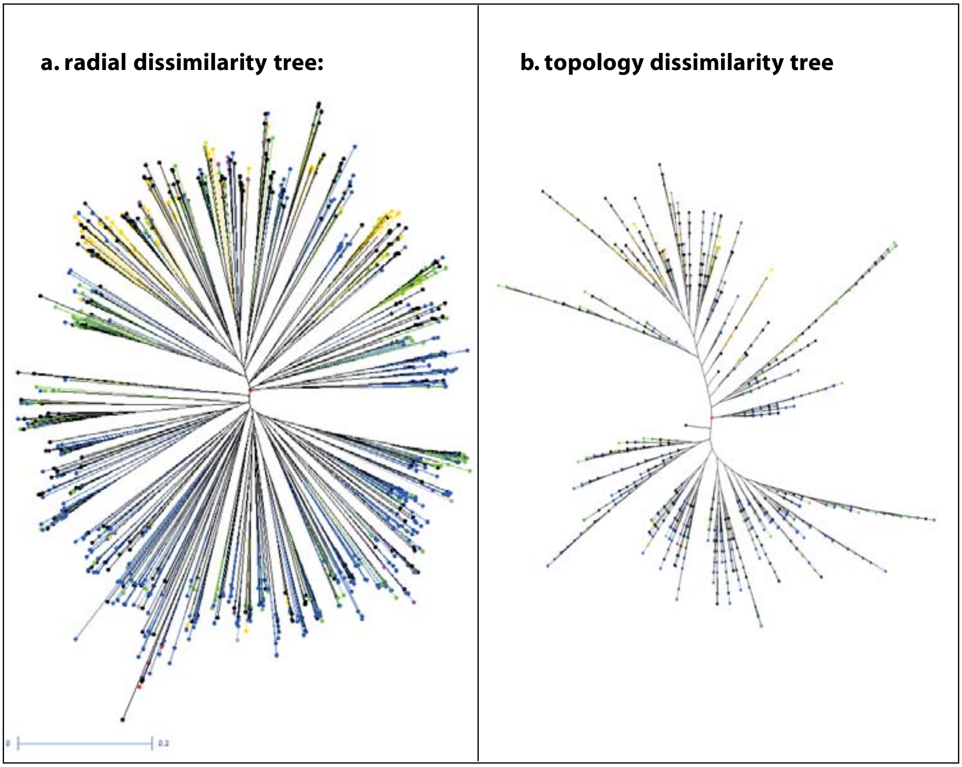
Population	Accessions (n)	Coeff. range	Coeff. limit	Unique cultivars	Morphotypes	Pure duplicates
Total	989	0.25-1.00	0.81	406	547	36
P1	634	0.25-1.00	0.81	250	362	22
P2	298	0.29-1.00	0.82	195	97	6
ISC-01	175	0.26-1.00	0.82	96	71	8
ISC-02	160	0.29-1.00	0.82	120	39	1
ISC-03	138	0.27-1.00	0.82	90	46	2
ISC-04	161	0.24-1.00	0.81	84	70	7
ISC-05	170	0.33-1.00	0.83	117	49	4
ISC-06	58	0.35-1.00	0.84	52	6	0
ISC-07	70	0.28-1.00	0.82	60	9	1
ISC-08	57	0.25-1.00	0.81	49	8	0

Analysis based on SSR marker data generally provided a more rigid means of classification, recognizing lower total numbers of unique cultivars, compared with analysis based on morphological descriptor data for the same farmer family subpopulations (ISC-01 to ISC-08). The total size of molecularly distinct cultivar pools ranged between 49 and 120 unique cultivars for sampled and analyzed farmer family subpopulations. This result reaffirms that households in Huancavelica maintain high levels of cultivar diversity within their potato crop.

The two geographically distanced subpopulations contain 250 (P1) and 195 (P2) unique cultivars. The difference of 55 unique cultivars may in part be a consequence of the initial number of accessions considered: 624 (P1) versus 298 (P2). Still, the total size of both cultivar pools, geographically distanced by approximately 90 kilometers, is appreciable and suggests that both areas can be considered as diversity "hotspots" for the cultivated potato.

Considerable molecular diversity also exists within the overall regional population (fig. 2.3). Most accessions were molecularly distinct with only 36 pure duplicates encountered within the total population consisting of 989 accessions. A total of 406 molecularly distinct and unique cultivars, belonging to clusters showing more than 25% dissimilarity, were identified. No species specific clusters were observed.

Figure 2.3: Unweighted Neighbor Joining (NJ) dissimilarity tree constructed with DARwin 4.0 and its topology (Jaccard's coefficient) for 989 accessions representing the total fingerprinted population (18 SSR primers)



* The scale bar (0–0.1) represents the level of dissimilarity; black = accessions without species ID, dark blue = *S. tuberosum* subsp. *andigena*, grey = *S. tuberosum* subsp. *tuberosum* (hybrids), light green = *S. chaucha*, orange = *S. goniocalyx*, purple = *S. stenotomum*, red = *S. juzepczukii* and *S. curtilobum*

Polymorphic Information Content (PIC) values show slight differences between populations, depending on the specific subpopulation and SSR marker, concerning polymorphism (table 2.9). A total of 181 alleles were detected within the overall population of 989 fingerprinted accessions; 22.7% of these were rare with a frequency of less than 1.0% (table 2.10). Subpopulation P1 contains more alleles that are both rare and unique[5] compared to subpopulation P2 (table 2.11). Five out of eight farmer family subpopulations contained alleles unique to these populations at percentages between 0.7 - 4.0%.

[5] Uniqueness is defined as the presence of specific alleles within a single subpopulation only, either within P1 compared with P2 or ISC-01 till ISC-08 compared among each other.

Table 2.9: Polymorphic Information Content (PIC) by subpopulation and SSR marker

Subpopulation / SSR marker	P1	P2	ISC-1	ISC-2	ISC-3	ISC-4	ISC-5	ISC-6	ISC-7	ISC-8
Accessions (n)	634	298	175	160	138	161	170	58	70	57
STM0019a	0.680	0.764	0.752	0.720	0.729	0.759	0.726	0.789	0.785	0.779
STM0019b	0.575	0.597	0.562	0.607	0.557	0.546	0.537	0.648	0.646	0.604
STGBSS	0.814	0.807	0.808	0.807	0.812	0.824	0.807	0.807	0.803	0.809
STM0037	0.710	0.727	0.744	0.697	0.708	0.669	0.752	0.670	0.675	0.757
STM0031	0.689	0.707	0.694	0.681	0.671	0.704	0.718	0.664	0.702	0.731
STM1052	0.781	0.779	0.780	0.780	0.778	0.776	0.783	0.770	0.761	0.770
STM1106	0.799	0.801	0.799	0.783	0.798	0.791	0.804	0.792	0.783	0.776
STM5127	0.832	0.831	0.820	0.836	0.836	0.831	0.832	0.833	0.817	0.819
STG0006	0.615	0.602	0.585	0.629	0.621	0.618	0.600	0.616	0.593	0.588
STG0010	0.622	0.622	0.617	0.622	0.605	0.640	0.643	0.584	0.582	0.683
STG0020	0.796	0.798	0.783	0.796	0.780	0.815	0.795	0.809	0.790	0.823
STI0003	0.661	0.681	0.650	0.628	0.667	0.694	0.673	0.654	0.716	0.739
STI0014	0.682	0.695	0.680	0.676	0.670	0.699	0.696	0.689	0.686	0.672
STI0022	0.649	0.686	0.638	0.651	0.650	0.656	0.702	0.661	0.649	0.677
STI0023	0.718	0.696	0.676	0.681	0.754	0.748	0.692	0.637	0.734	0.821
STI0030	0.793	0.808	0.786	0.789	0.801	0.794	0.808	0.810	0.799	0.814
STI0032	0.718	0.712	0.719	0.735	0.696	0.708	0.715	0.705	0.702	0.718
STI0036	0.740	0.754	0.716	0.744	0.745	0.748	0.746	0.751	0.765	0.765

Table 2.10: Summary of relative allele frequencies[1] (%) by population

	Accessions (n)	Frequent ($f \geq 10\%$)		Moderately frequent ($f < 10\%$)		Scarce ($f < 5\%$)		Rare ($f < 1\%$)	
		No.	%	No.	%	No.	%	No.	%
Total	989	81	44.8	19	10.5	40	22.1	41	22.7
P1	634	80	44.2	17	9.4	39	21.5	45	24.9
P2	298	84	46.4	18	9.9	32	17.7	47	26.0
ISC-01	175	76	42.0	22	12.2	39	21.5	44	24.3
ISC-02	160	82	45.3	12	6.6	35	19.3	52	28.7
ISC-03	138	79	43.6	20	11.0	25	13.8	57	31.5
ISC-04	161	81	44.8	18	9.9	35	19.3	47	26.0
ISC-05	170	83	45.9	16	8.8	28	15.5	54	29.8
ISC-06	58	87	48.1	15	8.3	23	12.7	56	30.9
ISC-07	70	83	45.9	14	7.7	38	21.0	46	25.4
ISC-08	57	86	47.5	19	10.5	32	17.7	44	24.3

[1]= (total number of specific alleles by subpopulation / total number of accessions by subpopulation) x 100%

Table 2.11: Number and percentage of alleles unique to the two geographically distanced[1] and eight farmer family[2] subpopulations

	Accessions / Alleles			Unique alleles by population and relative abundance				
	Accessions (n)	Alleles present (n)	Alleles not present (n)	Moderately frequent + unique (n)	Scarce + unique (n)	Rare + unique (n)	Total unique alleles (n)	Unique alleles[3] (%)
P1	634	177	4	0	9	15	24	13.6
P2	298	155	26	0	1	1	2	1.3
ISC-01	175	151	30	1	4	1	6	4.0
ISC-02	160	142	39	0	1	2	3	2.1
ISC-03	138	145	36	0	0	1	1	0.7
ISC-04	161	148	33	1	0	3	4	2.7
ISC-05	170	139	42	0	0	0	0	0.0
ISC-06	58	125	56	0	0	0	0	0.0
ISC-07	70	135	46	0	0	0	0	0.0
ISC-08	57	137	44	0	2	0	2	1.5

[1] uniqueness of alleles within P1 and P2 are based on the comparison of these two geographically distances subpopulations; [2] uniqueness of alleles within ISC-01 till ISC-08 are based on the comparison of these eight farmer family collections; [3] = (total unique alleles / alleles present) x 100%

Analysis of Molecular Variance (AMOVA) shows that in case of the two geographically distanced subpopulations P1 (central Huancavelica) and P2 (southern Huancavelica) the principal source of variation is encountered within the farmer family subpopulations (ISC-01 till ISC-07) that compose P1 and P2 (table 2.12). Molecular variance among subpopulations P1 and P2 and among subpopulations within P1 and P2 are limited sources of variation.

Table 2.12: Comparison of geographically distanced subpopulations P1 and P2 (AMOVA)

Source of variation	d.f.	Sum of squares	Variance components	Percentage of variation
Among subpopulations P1 / P2	1	48.060	0.031 Va	0.19
Among subpopulations within P1 / P2	5	172.902	0.142 Vb	0.87
Within subpopulations ISC-01 till ISC-07	925	14935.848	16.147 Vc	98.94
Total	931	15156.810	16.320	100

Fixation Indices:	Significance test (1023 permutations):
FSC: 0.00874	Vc and FST / P= <0.001
FST: 0.01062	Vb and FSC / P= <0.001
FCT: 0.00190	Va and FCT / P= 0.082

Similar results were encountered when comparing the structures of the farmer family subpopulations ISC-01 to ISC-08 (table 2.13). The principal source of variation is found within rather than between these subpopulations. This indicates that even though the number of accessions supplied by each farmer family differed considerably (min. 57 / max. 175), relatively few pure duplicates were encountered within the total population (n=989), and five out of eight farmer family subpopulations contained 1 to 6 unique alleles, most alleles are shared within the 8 farmer family subpopulations studied.

Table 2.13: Comparison of farmer family subpopulations ISC-01 till ISC-08 (AMOVA)

Source of variation	d.f.	Sum of squares	Variance components	Percentage of variation
Among subpopulations ISC-01 till ISC-08	7	272.339	0.188 Va	1.15
Within subpopulations ISC-01 till ISC-08	981	15899.743	16.208 Vb	98.85
Total	988	16172.082	16.396	100

Fixation Index:
FST: 0.01146

Significance test (1023 permutations):
Va and FST / P= <0.001

2.3.4 Comparison of molecular and morphological diversity of *in-situ* collections

Table 2.14 compares the number of unique cultivars, morphotypes and pure duplicates found through analysis of a complete dataset with both molecular and morphological data (n=679 accessions). Results are presented at the following scales: a. farmer family subpopulations, b. two geographically distanced subpopulations (P1 / P2; n= 406 / 240), c. overall regional population (n=679). Results based on a similar analysis with morphological versus SSR marker data differ considerably. The analysis of morphological data results in higher levels of diversity or more unique cultivars compared to molecular data.

Table 2.14: A comparison of diversity based on morphological and fingerprinting dendrograms

Pop.	N	Morphological descriptors					Molecular markers				
		Coeff. Range	Coeff. limit	Unique cultivars	Morpho-types	Pure duplic.	Coeff. Range	Coeff. limit	Unique cultivars	Morpho-types	Pure duplic.
ISC-01	143	0.00-1.19	0.30	132	11	0	0.27-1.00	0.82	85	54	4
ISC-02	107	0.00-1.16	0.29	99	8	0	0.31-1.00	0.83	86	21	0
ISC-03	60	0.00-1.16	0.29	59	1	0	0.28-1.00	0.82	44	15	1
ISC-04	96	0.00-1.13	0.28	93	3	0	0.24-1.00	0.81	57	34	5
ISC-05	138	0.00-1.16	0.29	122	16	0	0.33-1.00	0.83	92	42	4
ISC-06	47	0.00-1.04	0.26	46	1	0	0.37-1.00	0.84	44	3	0
ISC-07	55	0.00-1.04	0.26	54	1	0	0.29-1.00	0.82	47	8	0
ISC-08	33	0.00-1.02	0.26	33	0	0	0.25-1.00	0.81	27	6	0
P1	406	0.00-1.18	0.30	353	53	0	0.27-1.00	0.82	184	209	13
P2	240	0.00-1.14	0.29	208	32	0	0.29-1.00	0.82	154	81	5
Total	**679**	**0.00-1.16**	**0.29**	**567**	**112**	**0**	**0.27-1.00**	**0.82**	**312**	**346**	**21**

Mantel tests were used to compare matrices based on of morphological (descriptor) versus molecular (SSR marker) data (table 2.15). The correlations between the morphological and molecular matrices (direct and cophenetic) were limited and negative for all populations. This implies the two kinds of datasets and their matrices stand on their own. On the other hand, matrix correlations values (R) of similarity versus cophenetic matrices of morphological and molecular datasets are positive and relatively high, indicating robustness of matrices obtained through either morphological or molecular analysis.

Table 2.15: A comparisons of morphological (descriptor) and molecular (SSR) matrices with the Mantel test

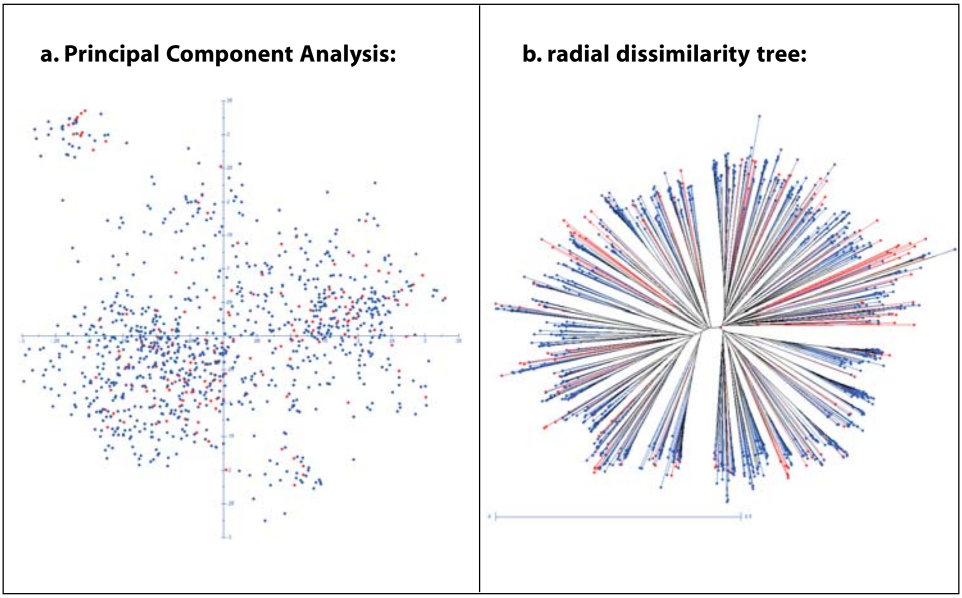
Population	N	R morphological versus molecular matrix		R similarity matrix versus cophenetic matrix	
		Matrix correlation (direct)	Matrix correlation (cophenetic)	Morphological (descriptor)	Molecular (SSR marker)
ISC-01	143	-0.13	-0.10	0.73	0.81
ISC-02	107	-0.10	-0.09	0.75	0.72
ISC-03	60	-0.07	-0.05	0.78	0.86
ISC-04	96	-0.16	-0.10	0.73	0.84
ISC-05	138	-0.15	-0.15	0.70	0.77
ISC-06	47	-0.20	-0.20	0.75	0.73
ISC-07	55	-0.19	-0.08	0.79	0.81
ISC-08	33	-0.02	-0.08	0.79	0.88
P1	406	-0.11	-0.10	0.71	0.77
P2	240	-0.16	-0.14	0.69	0.73
Total	**679**	**-0.12**	**-0.09**	**0.69**	**0.74**

2.3.5 Comparison of molecular diversity of *in-situ* and *ex-situ* collections

Figure 2.4 shows the distribution of accessions from both collections in a Principal Component Analysis (PCA) and Unweighted Neighbor Joining (NJ) dissimilarity tree. Accessions from the *ex-situ* core collection are scattered evenly among both graphs indicating that the allelic diversity within the *ex-situ* core collection is a representative subset of the total *in-situ* diversity maintained by farmers in Huancavelica. Analysis of Molecular Variance (AMOVA) confirms that the principal source of variation is located within the *in-situ* and *ex-situ* collections (table 2.16). Only 1.16% of variation can be assigned to differences between both collections.

Several clusters located above 25% of the dissimilarity coefficient are composed entirely of accessions belonging to the *in-situ* population. Cultivar diversity within the department of Huancavelica is higher than diversity present in the geographically restricted subset of the *ex-situ* core collection. Only 6 groups of pure duplicates, compromising 8 accessions from the *ex-situ* collection and 12 accessions from the *in-situ* collection, are shared between both populations. Farmer families maintain unique genotypes (cultivars) characterized by specific combinations of alleles which are not necessarily present in the subset of the core *ex-situ* collection based on the geographical origin of its constituting accessions.

Figure 2.4: Graphic display of a Principal Component Analysis (PCA) and Unweighted Neighbor Joining (NJ) dissimilarity tree comparing the molecular diversity within the total *in-situ* collection (n=989; Huancavelica department) with a CIP's core *ex-situ* collection (n=173; Huancavelica, Ayacucho and Lima departments)



* dark blue = accessions belonging to the *in-situ* collection; red = accessions belonging to the *ex-situ* collection

Table 2.16: Comparison of *in-situ* and *ex-situ* populations (AMOVA)

Source of variation	d.f.	Sum of squares	Variance components	Percentage of variation
Among the *in-situ* and *ex-situ* populations	1	66.994	0.176 Va	1.16
Within the *in-situ* and *ex-situ* populations	1160	17470.597	15.061 Vb	98.84
Total	1161	17537.591	15.237	100

Fixation Index:
FST: 0.01157

Significance test (1023 permutations):
Va and FST / P= <0.001

2.4 Discussion and conclusions

Data confirms that contemporary species and infraspecific diversity of potato as maintained on-farm in the department of Huancavelica is high. Farmers maintain all levels of ploidy ($2n=2x=24$ to $2n=5x=60$) within their cultivar pools with tetraploids being most and pentaploids least abundant. This is a normal ploidy distribution pattern when compared with earlier collections in central Peru and CIP´s *ex-situ* collections (Hawkes, 2004; Huáman et al., 1997; Ochoa, 1999, 2003). The same is true for the relative frequencies of botanical species identified. *S. tuberosum* subsp. *andigena*, *S. chaucha* and *S. goniocalyx* are most abundant followed by *S. stenotomum*, *S. juzepczukii* and *S. curtilobum*. The number of diploid accessions belonging to

S. goniocalyx and *S. stenotomum* represented about a quarter (24.9%) of the total samples, confirming previous reports that central Peru is a center of genetic diversity of these two species. It is interesting to note that what farmers identified as native cultivar stocks also contained *S. tuberosum* subsp. *tuberosum*. Old improved cultivars of hybrid origin, while having disappeared from regional markets, are still maintained by farmers who have incorporated them in their "native" cultivar collections. There is no evidence of species loss with the notable exception of *S. phureja*. It seems that cultivation of *S. phureja* has diminished drastically, possibly because of direct replacement by improved cultivars which nowadays predominate in production areas below 3,400 m where *S. phureja* was traditionally grown. Limited dormancy, which farmers report to have led to the loss of seed when they had to temporarily abandon their homes during the years of rural violence, may have been another factor contribution to the species scarcity.

Morphological characterization suggests the overall regional cultivar pool consists of at least 557 unique cultivars. Individual households maintain as much as 160 unique cultivars contributing significantly to the overall regional total. In some villages such as Villa Hermosa, where high numbers of unique cultivars are conserved, numerous families living in the higher parts of the community (> 4,000 m) grow large numbers of cultivars. Yet, in other communities, such as Allato, relatively few locally recognized families conserve large cultivar stocks representing most of the diversity found in that particular community. Even in communities that are highly market integrated, such as Huayta Corral, total morphological diversity is still high. This can be partially explained by farmer consumer preferences. While farmers produce few commercial cultivars for the market they prefer complete cultivar mixtures (*chaqru*) for their own consumption. These complete cultivar mixtures are associated with quality traits such as texture and taste.

Molecular characterization with 18 highly polymorphic SSR microsatellite markers suggests the overall regional cultivar pool consists of at least 406 unique cultivars. The difference with morphological characterization can be partially explained by the total sample size used. While molecular characterization was done for 8 farmer family collections from 6 communities (n=989), morphological characterization was applied to 38 farmer family collections from 8 communities (n=2,481). However, results obtained through molecular characterization confirm that farmer family populations, geographically distanced subpopulations and the overall regional population are highly diverse in their cultivar content.

Analysis of Molecular Variance (AMOVA) shows that the principal source of variation is encountered within rather than between the farmer family subpopulations. Most alleles are shared among farmer family and geographically distanced populations, thus offering a buffer for stress that a particular subpopulation might be subjected to, such as hails, frosts or other extreme events that might cause the loss of specific allele combinations. On the other hand, the specific value of farmer family and geographically distanced subpopulations is also complementary in the sense that most contain both scarce to rare alleles and unique alleles restricted to particular subpopulations. Even though alleles unique to a particular subpopulation are relatively few in relation to the total number of alleles, their long-term and ongoing evolutionary contribution should be considered as potentially highly valuable. Final or "stable" subpopulations are exceptional within a context of on-farm conservation and the dynamic management of potato genetic resources in the hands of farmers, subject to seed flow, mutation and possibly gene flow, is arguably one of the principal added-values that make *in-situ* conservation and a proper understanding of its underlying processes so important.

Morphological versus molecular characterization of the same potato cultivar accessions is shown to have limited correlation among each other. Both result in robust dendrograms with high matrix correlation values (R) when comparing (dis)similarity against cophenetic matrices for each individual system of characterization. Yet, comparisons of dendrograms obtained with the different systems of characterization results in negative matrix correlation values. The two systems of characterization are based on different sets of tools and can be considered as separate but complementary. As expected, the use of 18 SSR microsatellite markers for characterization of the same (sub)populations resulted in a more rigid classification of unique cultivars when compared with characterization based on environmentally stable morphological character states. Morphological characterization is more sensitive to human error and potentially results in artificial higher diversity indices compared to molecular characterization when studying large cultivar populations. Yet, a comparative added-value of morphological descriptor use relates to its relative accessibility and inexpensive application by groups of researchers or crop conservationists without access to molecular technologies.

A comparison of the molecularly characterized *in-situ* population from Huancavelica with a geographically delimited subset of CIP´s *ex-situ* core collection from central Peru shows that a high proportion of allelic diversity (98.84%) is shared between both collections. The *in-* and *ex-situ* gene pools are highly complementary and at the allelic level the geographically delimited *ex-situ* core collection is highly representative of the contemporary on-farm potato genetic diversity maintained in Huancavelica. Genetic erosion, when defined as the loss of alleles in an on-farm setting, seems to be non-existent. On the other hand, farmer in Huancavelica conserve numerous cultivars or genotypes characterized by specific allele combinations not present in the geographically restricted *ex-situ* core collection. Part of this difference is likely related to the size of the two populations compared: 989 accessions *in-situ* versus 173 accessions *ex-situ*. Within the *ex-situ* collection this difference is probably covered by accessions from origins other than central Peru as duplicates and similar morphotypes have been excluded from the core collection (Huamán *et al.*, 1997). Further, *in-situ* conservation of potato genetic resources by Andean farmers is dynamic. It is probable that seed flows between Peru's departments within the period of original acquisition of the *ex-situ* collection, 20 to 30 years ago, and the time of collection of the *in-situ* population must have been considerable, changing the regional composition of genotypes in the process. Evolution within an *in-situ* context, through mutations or possible gene flow, may also have contributed to the encountered differences at the genotype level (Celis *et al.*, 2004; Hawkes, 1994; Johns and Keen, 1986; Quiros *et al.*, 1992). Allelic diversity is embedded within cultivar diversity and this research shows that farmers in Huancavelica are excellent custodians of both units of conservation.

3. Indigenous biosystematics of Andean potatoes: folk taxonomy, descriptors and nomenclature[1]

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Abstract

Indigenous biosystematics consists of subsystems of folk taxonomy, descriptor use and nomenclature. Folk taxonomy of Andean potatoes recognizes at least five ranks. The folk generic rank is composed of three taxa: *Araq Papa* (semi-wild / consumed), *Papa Tarpuy* (cultivated / consumed), and *Atoq Papa* (wild / not consumed). Folk specific taxa (= cultivar groups) and varietal taxa (= cultivars) are abundant within the generic taxon of *Papa Tarpuy*. Use categories and agroecological criteria do not constitute main differentiating factors. Folk varietal taxa cluster well when using formal morphological descriptors; folk specific taxa less so. A moderate concordance, albeit with considerable exceptions, exists between folk specific or varietal taxa and their genetic make-up as characterized with molecular markers (18 SSR microsatellites). The coherence of clustering in a dissimilarity tree (dendrogram) varies for each folk specific (9) or varietal taxon (2) considered.

Farmers use a repertoire of 22 plant and 15 tuber descriptors, each with specific character states in the Quechua language. Farmers are well-able to recognize specific cultivars based on aboveground plant parts only (without exposing tubers). Nomenclature is regionally consistent for common cultivars, while inconsistent for scarce cultivars. Primary cultivar names (nouns) generally refer to a folk specific taxon through predominant metaphorical reference to tuber shape. Secondary cultivar names (adjectives) predominantly provide direct reference to tuber color.

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3.1 Introduction

The effectiveness and sustainability of externally driven or interventionist *in-situ* conservation efforts rely on enhanced knowledge and understanding of what farmers actually do and why they do it. Therefore a good understanding of how farmers themselves classify, identify, and name, and consequently make an inventory of their crop genetic diversity, can enhance the communication interface between insiders (farmers) and outsiders (research scientists). The interface between what insiders and outsiders talk about when they refer to agrobiodiversity is largely defined by a thorough understanding of indigenous biosystematics.

The purpose of this chapter is to compare the system of indigenous biosystematics of Andean potatoes as maintained by farmers in the department of Huancavelica, Peru, with previously reported subsystems for others regions (e.g. Brush, 1980, 2004; Zimmerer, 1996). The chapter provides new angles of structural comparison for the folk taxonomical subsystem based on characterization with formal morphological descriptors, highly polymorphic molecular markers, and species identification. Moreover, special attention is given to the use of folk descriptors for cultivar recognition and naming, and the nomenclatural structure of cultivar names.

3.1.1 Defining and comparing indigenous biosystematics

While formal biosystematics of cultivated potatoes is still under dispute (see Huamán and Spooner, 2002; Spooner *et al.*, 2007), Quechua farmers in the Peruvian Andes employ an indigenous classification system that is based on hundreds of years of intense *in-situ* management of potato genetic resources. Human nature and instinct favor the classification of all things that surround us, be it our family structure, the foods we eat, or the natural environment. This is equally true for past and present civilizations, and scientific or "folk" communities and their inherent knowledge systems. The classification of the world around us, either in tangible (e.g. potato cultivars) or intangible (e.g. spiritual) representations, allows us to communicate its existence and define relative disorder as to make it more compliant with specific sociocultural contexts. Useful classification almost automatically implies a minimal level of group consensus. The basic terms and rules of systematic order have to be agreed upon and communicated. Objects have to be recognized and afterwards defined. This in turn implies that object definitions have to be communicable and transferable, through either language or symbols.

Indigenous biosystematics can be defined as the commonly applied and recognized folk wisdom of identifying, classifying, naming, and relating living organisms as practiced by a particular culture or ethnic group. Indigenous biosystematics consists of the following subsystems: folk taxonomy, folk descriptors, and indigenous nomenclature. Folk taxonomy consists of an increasingly inclusive or exclusive set of orders: folk ranks and taxa. Folk descriptors are morphological or complementary character states used to identify cultivars. Indigenous nomenclature involves systems of naming: logic, consistency, linguistic structures. Indigenous biosystematics is used in thisd chapter as the overarching term that pulls together the theoretical and practical basis of otherwise dispersed, and often synonymous, systems of folk taxonomy (Bellon and Taylor, 1993; May, 2005; McGuire, 2005, p.161; Zimmerer, 1996, p.197), folk botany (Berlin, 1999), folk botanical classification (Cozzo, 2002), folk classification (Martin, 2004, p.218), folk biological classification (Hunn, 1999b), folk biological taxonomy (Atran, 1999; Brown, 1985), ethnobiological classification (Berlin, 1992), ethnotaxonomy (Ballón Aguirre *et al.*, 1992, p.36; Cotton, 1996, p.256), ethnobotanical classification (Cotton, 1996, p.257), native taxonomy (Gade, 1975, p.205), and indigenous taxonomy (Rajasekaran and Warren, 1995). Scientific studies of indigenous biosystematics seek to unravel the categorization of folk ranks and taxa, the morphological character states, use, and other criteria applied in categorization, and the inherent meaning and logic as consistently applied to vernacular nomenclatures.

[2] Cultivar group = a group of properly named cultivars, based on one or more criteria (Spooner *et al.*, 2003).

Table 3.1 compares and contrasts formal and indigenous biosystematics. The two systems can be combined to assess the relationships between them for specific populations, either by relating vernacular names with formal species identification (e.g. Borgtoft *et al.*, 1998; Brack Egg, 1999; Wong *et al.*, 2002) or by comparing the genetic relatedness of cultivar groups[2] recognized by local informants (e.g. Emshwiller, 2006; Quiros *et al.*, 1990). Formal and indigenous biosystematics are arguably complementary, as they can be combined in order to obtain insights into the links of categorization rationales and systems applied to *ex-situ* collections maintained in genebanks and *in-situ* populations managed by farmers.

Table 3.1: Formal and indigenous biosystematics compared

	Formal biosystematics	**Indigenous biosystematics**
Origin	Linnaean taxonomy; Carolus Linnaeus (1707–1778 A.D.) publications of *Systema Naturae* (1735) and *Species Plantarum* (1753)	Probably as old as human history itself; Theophrastus (372–287 B.C.) recorded early Greek folk taxonomy
Epistemology	Disimbedded from social relations and thus considered to be objective and universal	Imbedded in sociocultural relations and specific contexts with a certain level of universal principals
Methodology	Taxonomy and botany based on predefined ranks and binomial nomenclature	Based on regional experience, expertise, and criteria
Tools	Diverse, ranging from the use of herbarium specimens, morphological descriptors, genetics, biochemistry, bioinformatics, and statistics	Mostly morphological character states based on characters visible to the eye, although other criteria such as use or taste may also be of importance
Regulation	International Code of Botanical Nomenclature (ICBN), International Code of Nomenclature of Cultivated Plants (ICNCP)	Imbedded within a culturally agreed upon system of "rules of the game" maintained by its users
Aims	Classifying living organisms, their taxonomic relationships, and evolutionary origin for scientific purposes and by universals criteria	Classifying living organisms and their perceived relationships by localized and culturally defined criteria
Language	Botanical Latin (universal)	Multilingual (context specific)
Transfer	Written	Mostly oral

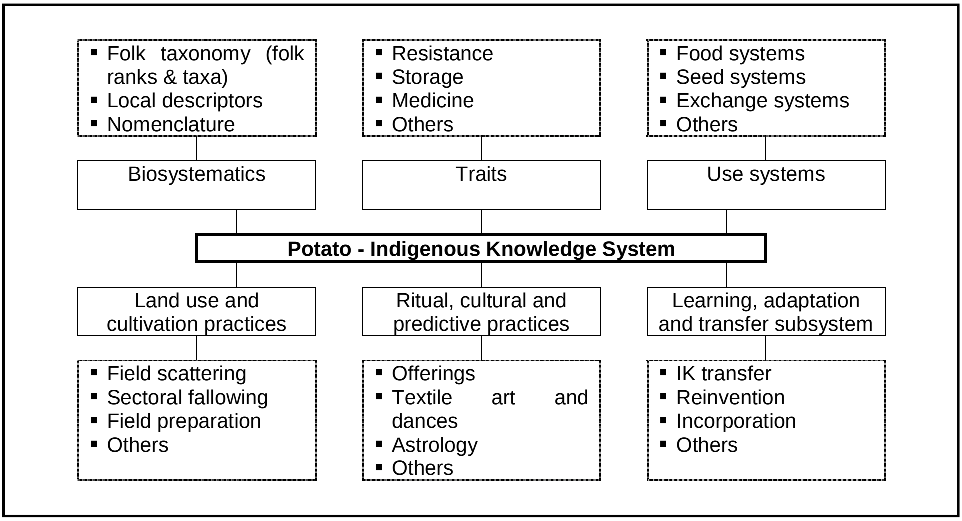
Source: own elaboration

3.1.2 Indigenous biosystematics as indigenous knowledge

Indigenous knowledge (IK), also sometimes referred to synonymously as traditional environmental knowledge (TEK) or collective knowledge (CK), is a valuable resource and priceless part of the world's cultural heritage (Alcorn, 1995; Hunn, 1999a; Laird, 2002; Prain, 1993; Slikkerveer, 1999). Indigenous biosystematics is a subsystem of the indigenous knowledge system associated with the potato (see fig. 3.1 for a simplified scheme). Indigenous knowledge systems are typically dynamic and adaptive to changing sociocultural environments. Newly invented or exotic knowledge can become incorporated, while other components may be replaced or become lost (McClatchey, 2005). Knowledge transfer from parents to children is experience-based and occurs predominantly in practical settings (Stobart and Howard, 2002). Depending on the specific knowledge domain, it may be linked to age, gender or social status (Howard, 2003).

Global concern about the state of indigenous knowledge has resulted in changing global and national policy and legislative environments (Brush, 1996). Debate about indigenous knowledge has also brought about dichotomies, at the center of which is a perceived divide between, for example, so called Western "scientific" and Andean "contextual" knowledge (Van der Ploeg, 1989). Where these two knowledge systems collide, a new reality emerges, which is neither necessarily ideologically neutral nor detrimental.

Figure 3.1: Simplified scheme of the potato indigenous knowledge system in the Andes



Source: own elaboration

3.1.3 Indigenous biosystematics of Andean potatoes in literature

Folk taxonomy

Weston La Barre (1947) provided one of the first written accounts of the "folk taxonomy" of Andean potatoes. Linguistic analyses of the nomenclature of 209 cultivar names led him to conclude that potato taxonomy is based upon a simple binomial scheme. Indeed, La Barre (1947, p.84) is concerned with linguistic taxonomy, something he clarifies in his article when writing "a nomenclature in which (linguistically speaking) a well developed native taxonomy inheres". La Barre (1947), like Hawkes (1947), draws attention to the logic structure[3] of indigenous variety names with a descriptive word (noun) for the (cultivar) group and a modifying adjectival word (often a color name) to distinguish the specific cultivar. La Barre (1947) also points out that potatoes are often divided into two major kinds, those used for simple cooking and those used for preparing freeze-dried *chuño*. This basic use-based classification into two groups is commonly considered a major differentiation factor within the folk taxonomical systems of Andean potatoes (e.g. Towle, 1961, p.85; Zimmerer, 1992, p.65; Zimmerer, 1995, p.136).

Zimmerer (1991b, p.31-33; 1996, p.195-197) reports potato folk taxonomy in Paucartambo (Cusco, Peru) to consist of four metacategories based on utilitarian objectives: boiling potatoes (native mealy cultivars), soup or peeling potatoes (watery improved cultivars), freeze-drying potatoes (native bitter cultivars), and money potatoes (watery improved cultivars). Furthermore, Zimmerer (1996) argues that because criteria such as mealy versus watery happen to match several traits that are key to the taxonomic divisions set out by biological science, the use

[3] Harrison (1989, p.181-184) draws attention to the ethnocentric nature of this kind of "logic", arguing that it reveals more about Hawkes's and our own thought patterns than those of the Andean peoples.

categories of Quechua cultivators actually correspond to scientific units. These scientific units in turn also fit with clearly defined farm spaces or production zones. Zimmerer (1996) also observes a gap or absence of folk ranks between the grand scale of use categories and the fine-scale distinction at which individual cultivars are identified.

Stephen Brush has reported widely on the folk taxonomy of Andean potatoes (Brush, 1980, 1992, 1998, 2004; Brush *et al.*, 1980; Brush and Taylor, 1992). Brush (2004, p.102-104) reports four ranks within Andean potato folk taxonomy: genus (*Papa*), species (*Atoq Papa*, *Araq Papa*, *Mikhuna Papa*, *Haya Papa*), variety, and subvariety. Furthermore, he points out that Andean potato farmers distinguish potatoes by tuber phenotype, ecology, and use. Varieties are distinguished primarily according to tuber characteristics while subvarieties are contrasted only by tuber color (Brush, 2004). Brush (2004) also notes that farmers contrast modern potato varieties that have been introduced since 1950 with local or native varieties.

Folk descriptors

Accounts of the use of folk descriptors (plant morphological character states) and their importance as a component of the indigenous biosystematics of Andean potatoes are scarce. Formal descriptors for Andean potatoes had already been developed early in the twentieth century (Soukup, 1939) and have been improved at several instances (Huamán *et al.*, 1977; Huamán and Goméz, 1994; Gómez, 2000). However, morphological characters used and recognized by farmers, either for flowering plants or tubers, have been little studied. It has been suggested that Andean farmers are not able to recognize potato cultivars without exposing tubers. Hawkes (1947, p.222) literally states "when seeing a plant growing in the field and wishing to know the variety, very few Indians are able, in my experience, to name it without exposing some of the tubers". Gade (1975, p.205) mentions that the flower, leaf, or plant form are of no significance in the folk botany of Andean potatoes. Brush (2004, p.103) points out that varieties are distinguished primarily according to tuber characteristics and that only in rare cases non-tuber characteristics such as stem or flower color are involved. The literature suggests that native cultivar names are largely based on tuber characteristics (La Barre, 1947; Ballón Aguirre *et al.*, 1992; Ballón Aguirre and Cérron-Palomino, 2002). However, this does not necessarily imply that farmers do not use other plant characters to distinguish and recognize cultivars.

Nomenclature

Registers and accounts of vernacular nomenclature are among the earliest and most abundant evidence of indigenous potato biosystematics. A few years after the conquest of the Inca Empire, chroniclers provided written evidence of nomenclature applied to potatoes. These accounts are mostly registers of general names applied to the potato. Only in few cases did they include references to infraspecific diversity such as cultivars (e.g. Bertonio, 1612). At the time of the conquest, just as today, Quechua and Aymara were the most widely spoken Andean languages (Chirinos, 2001; Rojas, 1998). General Quechua words applied to potato are *Papa* and *Akshu* (table 3.2). The word *Papa*, referring to the Quechua word for the cultivated potato, was reported by Cieza de León (1553), De Acosta (1590), De la Vega (1609), De Molina (c. 1570–1584), De Ondegardo (c. 1560), De Zárate (1555), González Holguín (1608), Guamán Poma de Ayala (1583–1613), Polo de Ondegardo (c. 1560), and Vázquez de Espinoza (c. 1629). *Papa* is still the most common Quechua[4] word used for the potato crop. It is used throughout the Andes and has been incorporated more widely into the Latin American Spanish vocabulary.

The word *Papa* is also commonly used as a direct reference to wild or semi-wild potato species (*Solanum* sect. *Petota*). At the same time it is also used to refer to a broader group of plants, most of which produce roots and tubers. Examples, mentioned by Soukup (1994) and Brack Egg (1999),

[4] Hawkes (1947) and Ballón Aguirre and Cerrón-Palomino (2002) provide ample discussion on the origin and use of the word *Papa* in Quechua.

include Papa Caribe (*Dioscorea bulbifera*), Papa Ckora (*Stachys* spp.), Papa China (*Colocasia* spp., *Xanthosoma* spp.), Papa Cholón (*Dioscorea* spp.), Papa de Cantón (*Colocasia* spp.), Papa de Montaña (*Dioscorea trifida*), Papa Semitona (*Dioscorea* spp.), Papa Japonesa (*Colocasia* spp., *Xanthosoma* spp.), Papa Lisa (*Ullucus tuberosus*), Papita de San Juan (*Begonia* spp.), and Sacha Papa (*Philodendron lechlerianum*). Therefore, it is a generic term that is most commonly but not exclusively applied to the cultivated potato.

Table 3.2: Quechua and Aymara generic names for the potato

Language	Term	Written variants	Present-day use
Quechua	*Papa*		Throughout the Andean region, commonly used both by Quechua and Spanish speakers
	Akshu	*Ajsu, Acsu, Acczu*	Used only in the department of Junin, central Peru.[5] Used by Quechua speakers (Chinchaysuyo dialect)
Aymara	*Choque*	*Choke, Cchoqque, Chu'uqi*	Altiplano region: southern Peruvian highlands and Bolivia. Used by Aymara speakers
	Amqa	*Amka, Amcca, Amkha*	Scarcely used in some local Aymara dialects

Sources: Ballón Aguirre and Cerrón-Palomino, 2002; Hawkes, 1947

The term *Akshu*, in reference to the Quechua word for the cultivated potato, has been reported in literature (see Ballón Aguirre and Cerrón-Palomino, 2002; Brack Egg, 1999, p.467; Brack Egg, 2003, p.120; Brush, 1980, p.41-42; Brush *et al.*, 1980, p.10-12; Cárdenas, 1989, p.35; Carranza Romero, 2003, p.33; Krenmayr *et al.*, 2000; Patrón, 1902; Soukup, 1994, p.382). Its use is limited to central Peru and originates[6] prior to 1560. Brush (1980, p.41-42) and Brush *et al.* (1980, p.10-12) initially used the term *Akshu* in a description of potato folk taxonomy, but changed *Akshu* for *Papa* in later publications while maintaining the same basic scheme of folk ranks and taxa (Brush, 1992; Brush, 1998, p.123; Brush, 2004, p.104; Brush and Taylor, 1992, p.233).

General terms for the potato in the Andean Aymara language are *Choque*[7] (*Ch'uqi* in modern orthography) and *Amqa* (table 3.2). The word *Choque* (potato) is cited in Arnold and De Dios Yatipa (1996), Brack Egg (1999, p.467; 2003, p.120), Cárdenas (1989, p.35), Christiansen (1967, p.15), Hawkes (1947, p. 212), La Barre (1947, p.87), Patrón (1902), and Soukup (1939, p.63; 1994, p.382). Reported by Bertonio[8] (1612), its meaning was translated in Spanish as "*papas, comida ordinaria de los indios*", which in turn translates in English as "potatoes, ordinary food of the Indians" (Ballón Aguirre and Cerrón-Palomino, 2002, p.38). Contemporary use of the word *Amqa* (Ballón Aguirre and Cerrón-Palomino, 2002, p.48–49; Bertonio, 1612; Cárdenas, 1989, p.35; Hawkes, 1947, p.212)

[5] Carranza Romero (2003, p.33) also reports the use of *Akshu* in the department of Ancash, while Quesada (1975) mentions its use in the department of Cajamarca (Northern Peru).

[6] Hawkes (1947, p.211) mentions that: "in a vocabulary of the Chinchaysuyo language (1603) [should be dialect], Jean de Figueredo mentions the word *Acsu* = papas". Ballón Aguirre and Cerrón-Palomino (2002, p.36), when referring to the *Lexicón o Vocabulario de la Lengua General del Peru* written by Fray Domingo de Santa Tomas and published in 1560, mention that the text includes <*Acssu*> "*papas, manjar de los indios*", which roughly translated as "potatoes, delightful food for the Indians".

[7] Hawkes (1947, p.212) indicates that *Choque* may refer specifically to the raw (uncooked) potato. This is contradicted by Arnold and De Dios Yatipa (1996, p.434) who mention that the word means both potato and raw things in general. La Barre (1947, p.87) also considered a specific meaning for the word *Choque* when writing: "Aymara divide all potatoes in two major kinds, *Chchoqhe* (which may be eaten after simple cooking) and *Lukki* (which are bitter and inedible unless frozen, fermented, and dried into food called *chuñu*)". This in turn is contradicted by Hawkes (1947, p.212), who wrote "I encountered the word *choke* eight times; these sorts were bitter and were also known as *Luki*". However, common opinion considers the word *Choque* to be a general term for potato.

[8] One of the most cited works, because of its importance as an early register of Aymara potato nomenclature, is Bertonio's (1612) dictionary of Aymara. This dictionary lists several potato and cultivar names, and other terms related to the crop. More than half a century ago, Hawkes (1947, p.206) wrote "certain classes of potatoes mentioned by Bertonio are still in use at present day". Brush (2004, p.102), referring to the same dictionary, points out that "while it is unlikely that similarly named varieties grown today are biologically the same as those mentioned four centuries ago, the persistence of varietal names for fifteen to twenty generations of farmers is remarkable".

seems to be extremely rare[9]. Other general Aymara terms reported for the cultivated potato are *Kea* (Christiansen, 1967; Patrón, 1902) and *Apharu* (Brack Egg, 1999; Soukup, 1994). Both cases concern incorrect translations from Bertonio's (1612) dictionary[10].

General words for the cultivated potato in numerous indigenous Latin American languages other than Quechua or Aymara have been reported (table 3.3). Quechua, Aymara and Spanish names applied to diverse semi-wild potato species and special cases, such as escapes from cultivation, also offer a rich sample of Andean vernacular nomenclatures (see appendices II, III, and IV).

Table 3.3: General names for the potato in other indigenous languages

Language / ethnic group	Reported names for potato	Source
Aguaruna (Peru)	*Moy Papa*, *Pua*, *Quinqui*	Brack Egg (1999); Soukup (1994)
Araucano (Chile)	*Poñi*, *Poñu*	Cardenas (1989), Christiansen (1967)
Asháninka/Campa (Peru)	*Catzari*, *Impari*, *Maona*, *Mojaqui*, *Moski*, *Mutza*, *Tseri*, *Zanaro*	Brack Egg (1999); Hawkes (1947); Soukup (1994)
Chibcha (Colombia)	*Iomuy*, *Iomza*, *Yomsa*, *Yomuy*	Hawkes (1947), Cardenas (1989)
Colorado/Cayapa (Ecuador)	*Pulu*, *Pulyu*	Hawkes (1947)
Jacaru (Peru)	*Papa*	Belleza Castro (1995)
Páez (Colombia)	*Caca*, *Kaca*	Hawkes (1947)
Uru-Chipaya (Bolivia)	*Curao Kara*, *Kesia*	Brack Egg (1999); Soukup (1994)
Yuracare (Bolivia)	*Cotohue*, *Cuinire*, *Obe*, *Pospo*, *Puspu*, *Some*	Hawkes (1947)

Source: own elaboration

The rich nomenclature applied to potato cultivar groups and individual cultivars is especially relevant as a component of indigenous biosystematics because it is here where notable diversity is found. Unfortunately, early chroniclers did not register the Quechua and Aymara nomenclature of cultivar groups and individual cultivars in great detail. Some chroniclers did notice, but not list, infraspecific variability; for example Cieza de León (1553), quoted in Cabieses (1995, p.77), described various types of potatoes when writing "round, large … white, yellow, purple … excellent dish for the Indians and for some Spaniards".

Bertonio's (1612) list of cultivars is an exception. His list of Aymara cultivar names included *Puma Coyllu*, *Amajaa*, *Ahuachucha*, *Ppatticcalla*, *Nayrappoco*, *Vlla Talla*, *Allca Hamacorani*, *Allca Phiñu*, *Kusku*, *Vila Kapi*, *Huatoco*, *Apichu*, and *Ccullukauna*. Several aspects of this list are worth analyzing. First, some of the names are remarkably or exactly the same as those reported by La Barre (1947) and Soukup (1939). For example, *Phiñu* is considered a (cultivar) group by La Barre (1947) and includes the cultivar *Alqha Phiñu* reported as *Allca Phiñu* by Bertonio (1612). Second, some of the basic principles of assigning cultivar names are reflected in Bertonio's list of cultivar names. These include references to animals and animal parts, e.g. the puma as reflected in *Puma Coyllu* (Bertonio, 1612) and contemporary Quechua cultivar names such as *Puma(pa) Makin* (puma paw). Another example is the naming of cultivars after look-alike plant parts of other crop species, e.g. *Apichu*, the original Quechua name for the sweet potato, *Ipomoea batatas*

[9] Hawkes (1947, p.212) wrote "the word *Amka* seems to have died out". The possibility of the word *Amqa* still being used today is raised by Ballón Aguirre and Cerrón-Palomino (2002, p.39) when they state "for reasons that we ignore, the term <*Amca*>, which subsists in some local dialects on both sides of the Peruvian-Bolivian border, has been replaced in the general Aymara of Puno by <*Choque*>, which is the present general designation of the potato in this language".

[10] Bertonio's (1612) original translation of the word *Kea* was "potatoes that emerge when others are planted, for having remained below the soil". So the term *Kea* is specific and refers to reemerged potatoes from last years plantings, nowadays referred to as *Papa(s) Wacha(s)* or *Papa(s) Kipa(s)* in Quechua. The word *Apharu* was reported by Bertonio (1612) as meaning "*wild potato*" and has as such been correctly copied in other dictionaries (e.g. De Lucca, 1983).

(Herrera, 1923, p.446; Herrera, 1942, p.180; Towle, 1961). This is also still applied in contemporary Quechua potato cultivar naming practices; e.g. in the case of the common potato cultivar *Camotillo*, named so after its resemblance with *Camote*, the current popular name of Mexican origin for sweet potato (Hawkes, 1947, p.219; Herrera, 1942, p.180).

Extensive lists of Quechua, Aymara, and Spanish cultivar names have been compiled from the beginning of the twentieth century onward, when potato collection expeditions in the Andes started. These include lists of original passport data, which accompanied the establishment of early genebank collections (e.g. Hawkes, 1947; Ochoa, 2003; Vargas, 1949, 1956). These lists are valuable sources of information for the structural or linguistic comparison of potato cultivar group and cultivar names. While some lists are stored in databases as passport data belonging to genebank collections, other regional lists have been published in literature (e.g. Ascue Muñoz, 2003, p.34; Asociación Urpichallay, 1999, p.82-83; La Barre, 1947, p.88-99; Pérez Baca, 1996, p.69-76; Schulte, 1996, p.139; Soukup, 1939; Tapia, 1999, p.43-45; Valdizán and Maldonado, 1922, p.307-323; Vargas, 1936, p.217-223).

3.2 Materials and methods

Research was conducted in 8 farmer communities from the department of Huancavelica (see Chapter 1).

3.2.1 Folk taxonomy

Folk taxonomy was researched with the use of: a. grouping exercises with farmers, b. participant observation, c. comparison of farmer-recognized groups with formal classification. Grouping exercises with farmer families were methodologically adapted from ethnobotanical field inquiries (Cotton, 1996; Grenier, 1998; Martin, 2004; Prance et al., 1997). The farmer family was the basic unit of inquiry and therefore discussion and consensus among family members was allowed. A total of 68 participatory grouping exercises were conducted with farmer families (June till Septemer 2004). Farmers were presented with a mixed fixed sample of tubers from cultivated, wild, and semi-wild potato species. Farmers and their families were asked to classify the sample into what they considered to be its taxonomic structure. The basic taxonomic structure was referred to as a "family structure" in order to make the basic question, about relative (non)relatedness and in- or exclusiveness, simple and in reference to a well-known institution. In addition to the physical grouping exercise, participants were asked about the names and characteristics of higher ranks, which cannot necessarily be represented by real samples. The constituents of each group, rank, or taxa, as recognized by the informants, were recorded, as were the main characteristics that defined these. Aditionally, participant observation as a social research method was applied (Jorgensen, 1989; Spradley, 1980).

Families with appreciable diversity were identified and seed-tubers of each farmer-recognized cultivar stored in net-bags. Accessions were labeled and on-farm trials with a minimum of five and a maximum of ten plants per accession installed (2003-2004 agricultural season). A total of 8 farmer family stocks from 6 research communities, representing a total of 1007 accessions or farmer-recognized cultivars, were morphologically and molecularly characterized. A subset of 165 accessions representing 16.4% of the total population and belonging to 11 farmer-recognized folk taxonomic entities - nine folk specific taxa or cultivar groups and two folk varietal taxa or unique cultivars - were selected for comparison with formal morphological descriptor data. The nine common folk specific taxa or cultivar groups, each represented by diverse cultivars, were *Gaspar*, *Ipillu*, *Llumchuy Waqachi*, *Masa Waqachi*, *Ñata*, *Pasña*, *Ritipa Sisan*, *Suytu*, and *Wayru*. The two common folk varietal taxa or individual cultivars, each represented by accessions from various farmer families, were *Peruanita* and *Sirina*. Farmers considered these cultivars as unique units and not part of a specific cultivar group. Morphological description was done with the International Potato Center's descriptor list, including its standard color card (Gómez, 2000; Huamán and Gómez, 1994). This formal list consists of 17 morphological descriptors with a total of 32 morphological character states, 18 of which are considered to be environmentally stable (appendix I). Berry color and berry shape were not recorded because of early frosts and consequent abortion of berries. A similarity analysis with an average taxonomic distance coefficient (DIST), Sequential Agglomerative Hierarchal Nested (SAHN) cluster analysis, and Unweighted Pair Group Method Arithmetic Average (UPGMA) clustering method was carried out for all 165 accessions using NTSYS-pc 2.1 software; none of the accessions had missing data.

A subset of 190 accessions[11] representing 18.9% of the total population was selected for comparison with molecular marker data. A total of 18 highly polymorphic microsatellite (SSR) loci were used for genetic fingerprinting: STM0019a, STM0019b, STGBSS, STM0037, STM0031, STM1052, STM1106, STM5127, STG0006, STG0010, STG0020, STI0003, STI0014, STI0022, STI0023, STI0030, STI0032, and STI0036 (Feingold *et al.*, 2005; Ghislain *et al.*, 2004; Milbourne *et al.*, 1998; Núñez *et al.*, 2005). The microsatellite loci covered the whole genome (12 chromosomes), covering a range of 6 to 17 alleles per SSR loci (average 10) and a PIC (Polymorphism Index Content[12]) range of 0.584 to 0.834 (average 0.726). Table 3.4 provides a summary of the SSR markers used, the number of alleles, allele sizes, and PIC encountered within the total population. Standard procedures as practiced at the International Potato Center (CIP) were applied, including DNA extraction with DNeasy 96 plant kits, high throughput genotyping with a LI-COR 4300 DNA Analysis System, and SSR allele scoring with SAGA Generation 2 software (LI-COR). A dissimilarity

Table 3.4: Summary of SSR marker coverage - number of alleles, range of alleles, and Polymorphic Information Content

SSR Name	Source (*)	Number of Alleles	Range of Alleles (bp)	PIC
STM0019a	SCRI	17	159– 213	0.756
STM0019b	SCRI	11	93–116	0.584
STGBSS	SCRI	10	140–157	0.813
STM0037	SCRI	11	89–133	0.728
STM0031	SCRI	8	185–211	0.702
STM1052	SCRI	7	226–263	0.783
STM1106	SCRI	10	130–196	0.800
STM5127	SCRI	13	248–291	0.834
STG0006	TIGR	8	148–178	0.610
STG0010	TIGR	7	176–186	0.630
STG0020	TIGR	13	139–169	0.800
STI0003	IDAHO	11	149–188	0.678
STI0014	IDAHO	7	136–154	0.688
STI0022	IDAHO	6	131–151	0.670
STI0023	IDAHO	14	172–230	0.726
STI0030	IDAHO	9	104–125	0.801
STI0032	IDAHO	10	127–148	0.717
STI0036	IDAHO	11	133–164	0.747

Source: Ghislain *et al.*, 2004; * SCRI (Scottish Crop Research Institute; Dundee, Scotland, UK), TIGR (The Institute of Genomic Research; Rockville, USA), IDAHO (University of Idaho; Moscow, USA)

[11] These 190 accessions are from the same original population (1007 accessions) from which the 165 accessions for comparison with morphological data were originally selected. The difference is caused by a lack of complete descriptor data in the case of the subset used for morphological comparison.

[12] The Polymorphism Index Content (PIC) was calculated with Nei's statistic (Nei, 1973, 1987): PIC=$1-\sum(p_i^2)$, where "p*i*" is the frequency of the *i*-th allele detected in all individuals of the population.

tree was built with complete data from all 190 accessions using an Unweighted Neighbor Joining (NJ) clustering method for a dissimilarity matrix calculated with the Jaccard's coefficient using DARwin 4.0 software[13].

3.2.2 Folk descriptors

Folk descriptors were researched with the use of: a. free and indicated listing exercises in farmer's mixed cultivar plots at flowering stage, b. free and indicated listing exercises with tuber samples of mixed cultivars (Cotton, 1996; Martin, 2004). Free listing involves informants (farmers) naming samples of flowering plants or tubers representing different cultivars, along with all characters (folk descriptors) used for recognition, according to their own order of priority without major researcher intervention. Indicated listing requires informants to provide the name and characters used for recognition of plants or tubers randomly pointed out by the fieldworker. These exercises involved independent sets of family-owned cultivar samples, except for indicated listing of tuber samples.

At flowering stage, individual informants (farmers) were asked to free list samples (flowering plants representing different native cultivars) growing on their own respective mixed cultivar plots (*chaqru* fields). First, informants were asked to identify and name (free list) any sample without exposing tubers. Second, for each sample listed, farmers were asked how they were able to identify it. All characters or farmer descriptors used for each individual sample were recorded. Third, each sample (plant) was labeled and at harvest time the farmer and fieldworker returned to the specific field to check the identity of each previously labeled sample while exposing the tubers. The match between initial identification at flowering stage and verification at harvest was recorded, either as correct or incorrect. Free and indicated listing exercises at flowering stage were conducted between January and March 2004 and 2005 respectively while verification of labeled plants through the exposure of tubers was conducted between May and June 2004 and 2005 respectively. A total of 101 informants free listed 879 samples, an average of 8.7 samples per farmer. Aditionally, separate indicated listing exercises at flowering stage were done with samples (flowering plants) randomly selected by the field workers. A total of 75 informants were shown 370 indicated samples, an average of 4.9 samples per farmer. The informants identified 297 samples by name using their own set of folk descriptors, an average of 4.0 samples per farmer. Again, for each sample the initial identity (local name) and farmer descriptors were recorded while the identity was verified against tuber samples at harvest.

Additional separate free and indicated listing exercises using tuber samples of mixed cultivars were done after harvest (May and August 2004 and 2005 respectively). Informants free listed (identified and named) samples (tubers representing different native cultivars) from family-owned stocks based on tuber characters only. Farmers were asked how, or by which tuber characteristics, they were able to identify and name each sample. All the names and tuber descriptors used by the different informants for each of the samples were registered. A total of 160 informants free listed and characterized 1351 samples, an average of 8.4 samples per farmer. Additionally a separate indicated listing exercise, using a fixed locally collected sample of 15 native cultivars consisting of five tubers per cultivar, was applied. A total of 160 informants listed and characterized 1766 indicated samples, an average of 11.0 samples per farmer.

3.2.3 Nomenclature

Nomenclature was researched applying: a. nomenclature surveys with regional fixed samples (tuber samples of 30 distinct native cultivars; May and August 2004 and 2005 respectively), b. basic ethnolinguistic analysis of regional names, c. participant observation. Informants (n=193)

[13] CIRAD-FLHOR, DARwin for windows version 4.0, Équipe de Mathématiques et Informatique Appliqées, 34398 Montpellier, Cedex 5, France, 2003.

were shown a regional fixed sample of 30 cultivar (minimum of five tubers per sample) and individual farmers were asked to name the samples they knew. All names reported were registered. Furthermore, a total of 1267 names corresponding to the native cultivar collections of 15 informants (farmers) from all eight communities were registered for basic ethnolinguistic analysis considering language, structure, and meaning. Duplicate names were considered as a single unit, leaving a total of 751 unique names for basic ethnolinguistic analysis. Additionally the practice of cultivar naming was observed during inventories, seed fairs, harvests, and conversations with farmers. During multiple instances general, specific, and directed questions were posed to farmers in order to obtain a better understanding of the logic of cultivar naming practices.

3.3 Results

3.3.1 Folk taxonomy

Folk taxonomical system

Figure 3.2 provides a basic scheme of the predominant folk taxonomical system as commonly recognized and used by Quechua farmers in Huancavelica. Ranks are ordered according to the universal scheme proposed by Berlin (1992). At the intermediate level *Papa* (potato) appears as a taxon that includes cultivated and wild species, cultivar groups, and specific cultivars. The same rank is shared with other taxa and includes general terms for other wild and cultivated plant complexes such as olluco (*Ullucus* spp.), mashua (*Tropaeolum* spp.), quinoa (*Chenopodium* spp.), and others. At the level of life forms, a more inclusive and higher rank, *Papa* (potato) is considered to belong to the taxon of *Yura* (herbaceous plants).

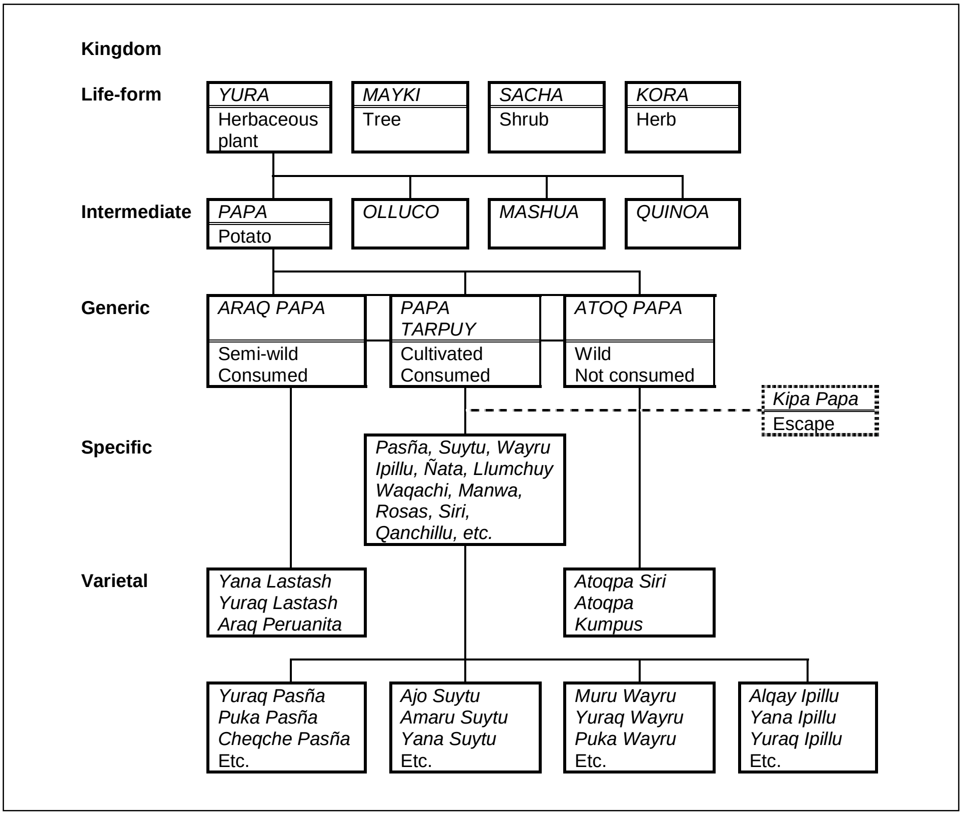
At the more exclusive level of folk generics, Quechua farmers commonly and widely recognize three well defined taxa. First, the folk taxon of *Papa Tarpuy*, which includes all cultivated potatoes, both its bitter and non-bitter variants, all of which are used for human consumption; second, the folk taxon of *Araq Papa*, consisting of a particular group of potatoes that grows in the wild, yet is collected for consumption; and third, the folk taxon *Atoq Papa,* which includes all wild relatives and is not consumed. These folk generic taxa were recognized by 54 of 68 families (79.4%) having participated in the ethnobotanical grouping exercises.

The taxon of *Papa Tarpuy* includes the cultivated species as commonly recognized by formal taxonomy of the cultivated potato and encountred in Huancavelica: *Solanum tuberosum* subsp. *tuberosum*, *S. tuberosum* subsp. *andigena*, *S. goniocalyx*, *S. stenotomum*, *S. chaucha*, *S. juzepczukii*, and *S. curtilobum*. All potatoes belonging to the taxon of *Papa Tarpuy* are domesticated and human-managed, and can normally not be found in the wild. An exception is leftover tubers that sometimes survive in the field and are classified as *Kipa Papa* or *Wacha* by farmers. The taxon is characterized by the fact that it entirely consists of domesticated or cultivated potatoes. Use aspects implied by relative bitterness and consequent end use for either fresh consumption or freeze-drying weren't important differentiating criteria at the folk generic level.

The folk taxon *Araq Papa*[14] consists of wild potatoes that are commonly collected and consumed by farmers. According to formal taxonomy these potatoes belong to the "cultivated" species *Solanum tuberosum* subsp. *andigena* (Ochoa, 2001, p.446). It is common to find *Araq Papa* as a weed in areas where maize is produced. The plant's root system typically has long stolons and thick tuber skin. The folk taxon is specifically characterized by its weediness or wild

[14] *Araq Papa* as a folk taxonomic entity is known throughout the Andes by different vernacular names, including *Papa Gentil* (central Peru), *Papa Curao* (Junin, Peru), *Chayka Papa* (Yauyos, Peru), *Tipono* (Venezuela), and *Lelekkoya* (Bolivia). See annex III.

Figure 3.2: Basic folk taxonomic scheme of the potato in Huancavelica



Source: grouping exercices (n=68)

state while at the same time being a significant source of food for collectors. Only on rare occasions is *Araq Papa* purposely planted or grown by farmers.

The folk taxon of *Atoq Papa*, literally meaning "fox potato", consists of wild potatoes that are not consumed by farmers. They may be used in traditional medicine but are not part of the food system. *Atoq Papa* is the generic Quechua name farmers commonly give to wild potato species found in Huancavelica, which are *Solanum amayanum*, *S. acaule*, *S. bill-hookeri*, *S. bukasovi*, *S. gracilifrons*, *S. medians*, and *S. huancavelicae* (Fuentealba, 2004; Ochoa, 1999, 2003; Salas, pers. comm.; Spooner *et al.*, 1999). The Quechua term *Atoq Papa*, or *Papa del Zorro* in Spanish, is commonly applied throughout the Peruvian Andes and relatively well registered in literature compared to other vernacular names (appendices II and III).

Informants generally recognized only one additional specific rank below the generic ranks of *Araq Papa* and *Atoq Papa*. Within *Araq Papa*, farmers recognized what they considered to be varieties, particularly in communities where farmers had access to maize-producing zones and consequently were familiar with *Araq Papa*. Names were specific to each community and only few informants were able to list 2 to 4 cases, e.g. *Yana Lastash* (black tubers), *Yuraq Lastash* (white tubers), and *Araq Peruanita* (yellow white tubers) in the case of the Allato community (fig. 3.2). Within *Atoq Papa* farmers also recognized few variants. This may be partially related to the fact that most wild potato species as recognized by formal taxonomy are endemic with limited distribution within Huancavelica. Also because regional morphological variability within the more widely distributed wild species *Solanum acaule* and *Solanum bukasovii* is limited. Informants generally were able to list only 2 to 3 cases, e.g. *Atoqpa Siri* and *Atoqpa Kumpus* in the case of the Villa Hermosa community (fig. 3.2).

Genetic and morphological diversity within *Papa Tarpuy* is exceptionally high and consequently the numbers of folk taxa and the diversity of vernacular names at the more specific levels - the folk specific and folk varietal ranks - were abundant. The folk specific rank contains multiple cultivar groups that are to a large extent named in accordance with their tuber shape. Table 3.5 provides a list with some exemplary common folk specific taxa (cultivar groups) and their respective folk varietal taxa (specific cultivars) as commonly recognized by farmers from Huancavelica. Depending on the specific family and community, a farmer may recognize 5 to 30 folk specific taxa (cultivar groups). Although many cultivars belong to a farmer recognized cultivar group, this is not necessarily always the case. The designation of a cultivar to a cultivar group varies among farmer families. The most numerous taxa within the folk taxonomical system are found at the level of the varietal rank. Folk varietal taxa are as numerous as the total amount of specific cultivars recognized by farmers; this may well be over 100 for some conservationist families. Figure 3.3 provides examples of 6 common folk specific taxa (cultivar groups) according to their typical tuber morphology while figure 3.4 shows 6 folk varietals (cultivars) belonging to the folk specific taxon *Pasña*.

Table 3.5: Examples of some folk specific and varietal taxa of cultivated potatoes (*papa tarpuy*)

Folk specifics					Folk varietals
Cultivar group	Vernacular nomenclature based on tuber morphology				Examples of some typical varietal taxa (native cultivars)
	Yes	No	Dir.	Indir.	
Gaspar	X			X	'Morado Gaspar', 'Muru Gaspar', 'Puka Ñawi Gaspar', 'Yana Gaspar', 'Yuraq Gaspar'
Ipillu		X			'Allqa Ipillu', 'Qillu Ipillu', 'Yuraq Ipillu'
Llumchuy Waqachi	X			X	'Azul Llumchuy Waqachi', 'Morado Llumchuy Waqachi', 'Muru Llumchuy Waqachi'
Manwa		X			'Yana Manwa', 'Yuraq Manwa'
Masa Waqachi	X			X	'Guinda Masa Waqachi', 'Puka Masa Waqachi'
Ñata	X		X		'Azul Ñata', 'Uqi Ñata', 'Yana Ñata'
Pasña	X			X	'Azul Ñawi Pasña', 'Chiqchi Pasña', 'Pillpintu Pasña', 'Puka Pasña', 'Qillu Pasña', 'Uqi Pasña', 'Yana Pasña'
Ritipa Sisan	X			X	'Uqi Ritipa Sisan', 'Yana Ritipa Sisan'
Rosas	X			X	'Muru Rosas', 'Puka Rosas', 'Qillu Rosas'
Siri		X			'Kumpus Siri', 'Yana Siri', 'Yuraq Siri'
Suytu	X		X		'Acero Suytu', 'Ajo Suytu', 'Amaru Suytu', 'Qala Suytu', 'Qillu Suytu', 'Suytu Alianza', 'Yana Suytu'
Tumbay		X			'Qillu Tumbay', 'Urqu Tumbay', 'Yuraq Tumbay', 'Puka Ñawi Tumbay', 'Qatun Tumbay'
Wayru		X			'China Wayru', 'Muru Wayru', 'Pichi Wayru', 'Puka Wayru', 'Qillu Wayru', 'Yana Wayru'

Figure 3.3: Six common folk specific taxa from Huancavelica

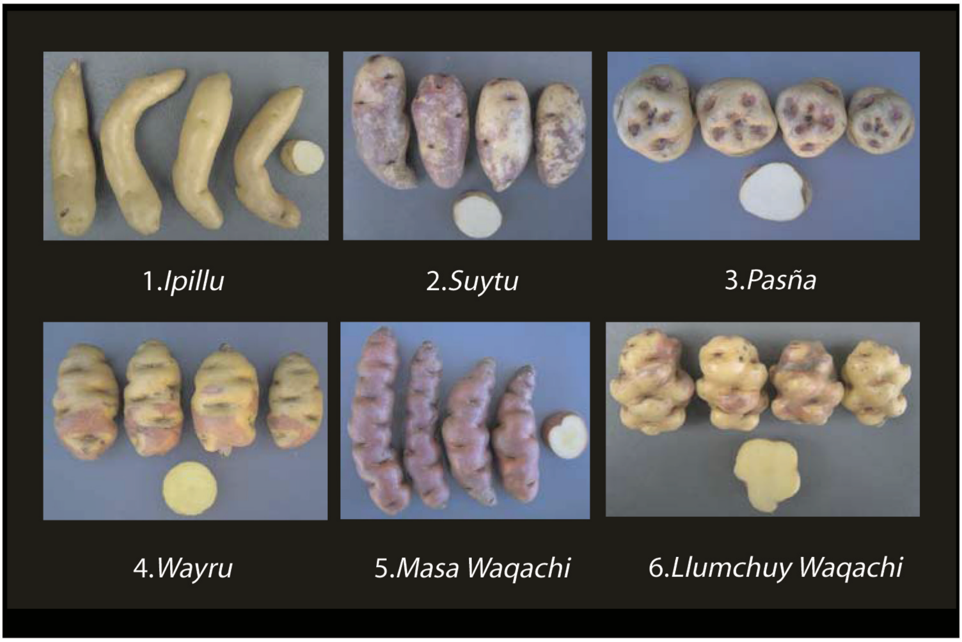
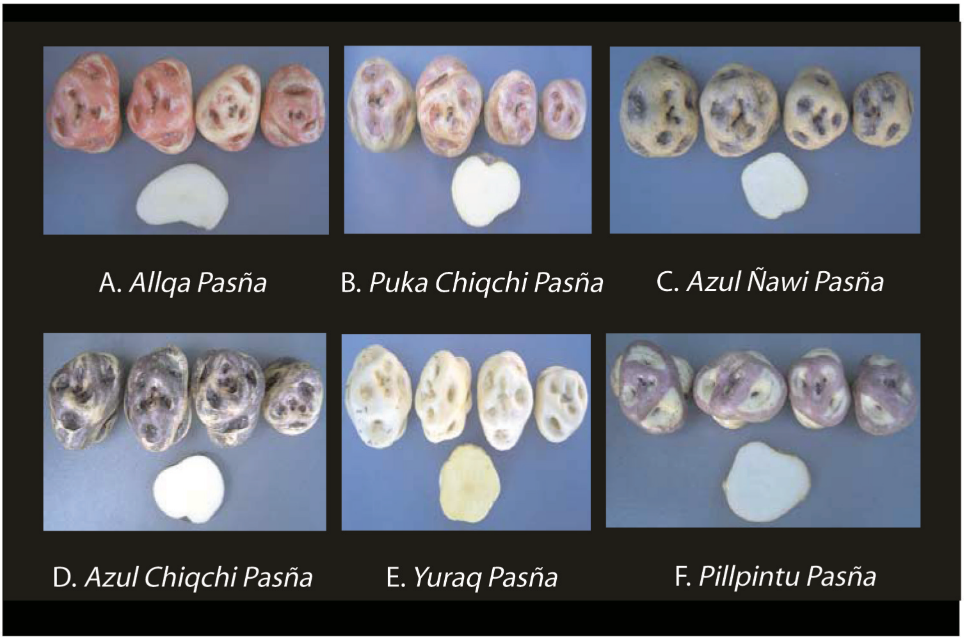


Figure 3.4: Six folk varietals (cultivars) belonging to the folk specific taxon *Pasña*



Folk specific and varietal taxa versus formal classification

A similarity analysis with 165 accessions belonging to 9 commonly recognized folk specific taxa (cultivar groups) and 2 folk varietal taxa (cultivars) was used to determine links between folk taxonomic classification and morphological characterization. Analysis of the similarity tree (dendrogram) focused on the level of coherent grouping of the accessions according to the folk taxa to which they belong (fig. 3.5). Two types of clusters were recognized in order to determine the coherence of grouping: *single predominant clusters* and *subclusters*. The first was used for a strict analysis that considers only accessions belonging to a single predominant cluster[15] per folk taxonomic entity. The second considers accessions belonging to the single predominant cluster and clear subclusters[16] per folk taxonomic entity. Figure 3.6 expresses the levels of coherent grouping per folk taxonomic entity as a percentage of the accessions belonging to a single predominant cluster or predominant and subclusters. Clustering by morphological similarities within a single predominant cluster is limited for all folk taxonomic entities with exception of the folk varietal taxa *Peruanita* and *Sirina* at 87.5% and 73.3% respecticely. Accessions belonging to folk specific taxa (cultivar groups) clustered at low levels of coherence, varying between a mimimum of 18.2% (*Gaspar*) and maximum of 62.5% (*Ñata*), for single predominant clusters. Thus overall morphological similarity within folk specific taxa, based on complete stable descriptor data, is limited.

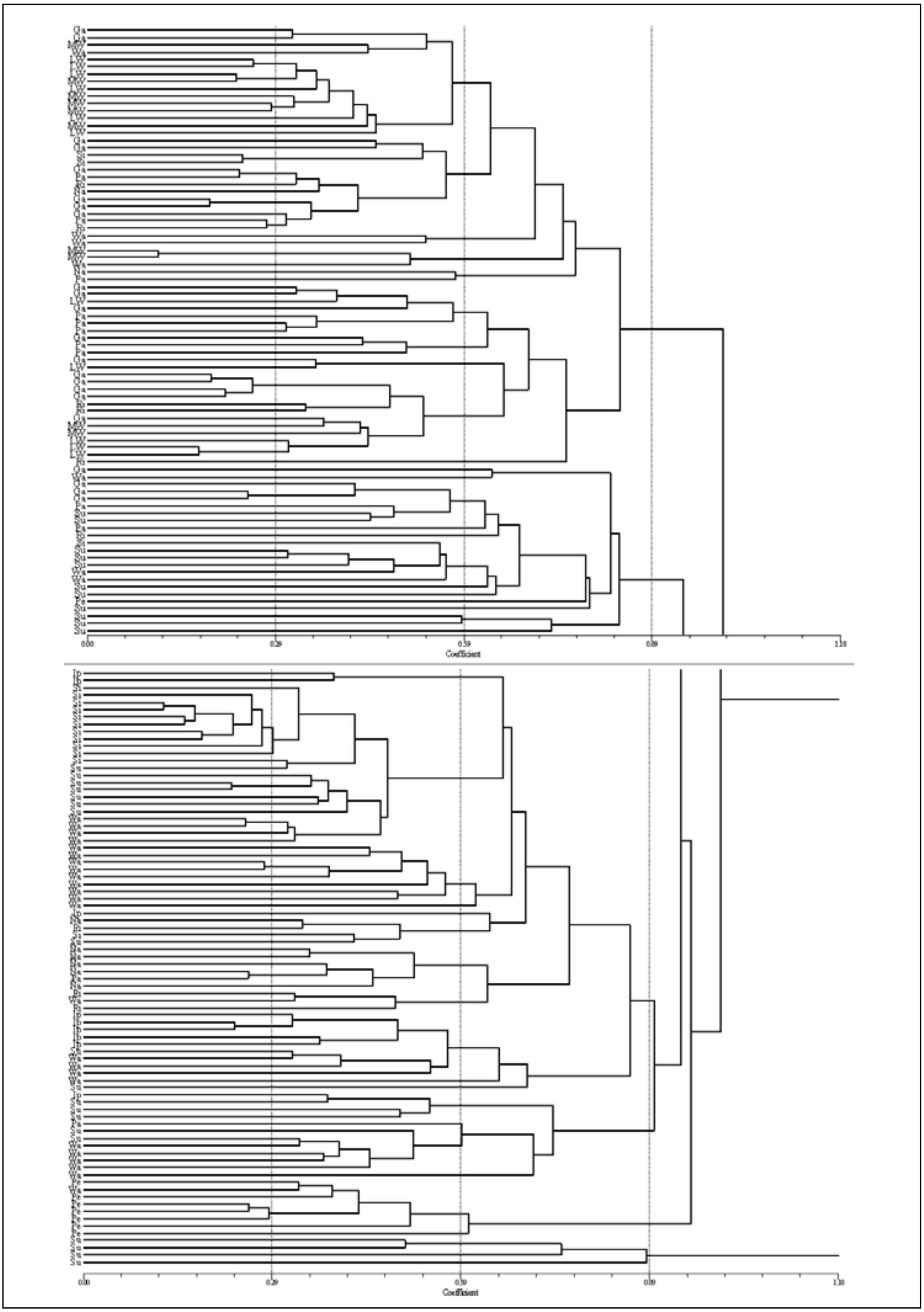
Several subclusters dominated by accessions from folk specific taxa can be observed in the dendrogram (fig. 3.5). These range from 5 subclusters for *Gaspar* and *Suytu* (maximum) to 1 subcluster for *Ñata* (minimum). The level of coherent grouping generally increases when all subclusters dominated by accessions from a single folk taxonomic entity are accounted for (fig. 3.6). This indicates that most folk-specific taxa are made up of small subpopulations that are morphologically distinct, yet share certain key characteristics that farmers use to distinguish them as belonging to a group. An additional similarity analysis with the same folk taxonomic entities using only tuber descriptors did not show higher levels of coherence when compared against the use of all stable morphological descriptors.

A dissimilarity analysis with microsatellite (SSR) data for 190 accessions belonging to the same 9 folk specific and 2 folk varietal taxa is shown in figure 3.7. Analysis focused on the level of coherent clustering of the accessions according to the folk taxa to which they belong. Figure 3.8 expresses the levels of coherence per folk taxonomic entity as a percentage of the accessions belonging to a single predominant cluster or predominant cluster and clear subclusters. These two types of analysis only resulted in different levels of coherence for the folk specific taxa *Gaspar*, *Suytu*, and *Wayru*. While each of these 3 cultivar groups had one predominant cluster, the *Suytu* group had 3 subclusters, the *Gaspar* group 2 subclusters, and the *Wayru* group 1 subcluster (fig. 3.8).

[15] Single predominant cluster = cluster with the highest (absolute) number of accessions of a specific folk taxonomic entity belonging to it and at the same time dominated by accessions of this entity (>50%).

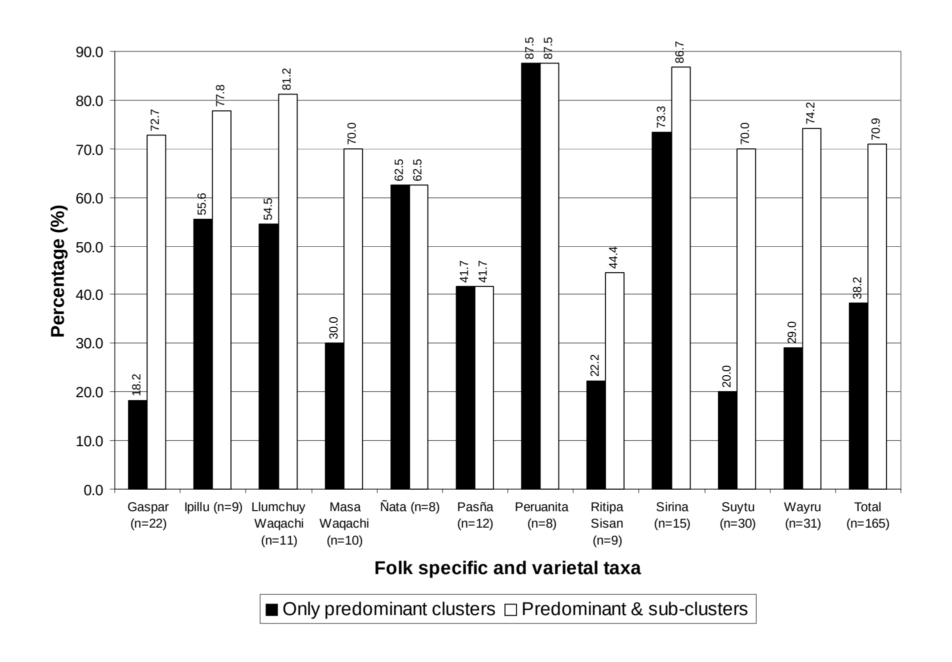
[16] Clear subclusters = secondary clusters with most of its pertaining accessions (>50%) belonging to the folk taxonomic entity concerned.

Figure 3.5: UPGMA dendrogram (DIST coefficient) for 165 accessions belonging to 9 cultivar groups and 2 individual cultivars based on environmentally stable morphological characters



* Ga=*Gaspar*, Ip=*Ipillu*, LW=*Llumchuy Waqachi*, MW=*Masa Waqachi*, Ña=*Ñata*, Pa=*Pasña*, Pe=*Peruanita*, Ri=*Ritipa Sisan*, Si=*Sirina*, Su=*Suytu*, Wa=*Wayru*

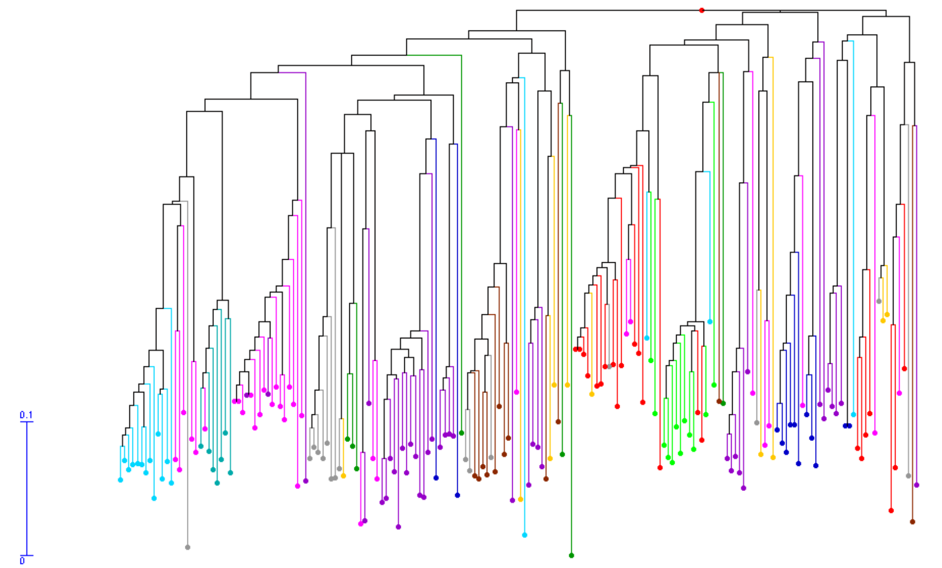
Figure 3.6: Level of coherent clustering of folk specifics and varietals with morphological descriptors



Overall, there is a moderate concordance between accessions recognized by folk taxonomy and microsatellite (SSR) markers. Over half (55.8%) of the total population (n=190) analyzed groups coherently when considering single predominant clusters, while over two-thirds (69.5%) of the total population groups coherently when considering both predominant and subclusters. In general, the consistency of clustering of accessions belonging to folk taxonomic entities in a single predominant cluster with SSR markers was higher compared to the same analysis based on morphological descriptor data. The folk varietal taxa *Peruanita* and *Sirina* clustered relatively well with 100% and 76.5% respectively (fig. 3.7 and 3.8).

Folk specific taxa also group, but with considerable exceptions. At a level of coherence higher than 50% for single predominant clusters this applies to 4 out of 9 folk specific taxa: *Gaspar*, *Ipillu*, *Llumchuy Waqachi* and *Ritipa Sisan*. In addition it applies to *Suytu* and *Wayru* when considering both predominant and subclusters. Accessions belonging to the folk specific taxa *Masa Waqachi*, *Ñata*, and *Pasña* show very limited levels of coherent clustering. A proportion equal to or higher than 50% of the total number of accessions belonging to each of these 3 cultivar groups is scattered along the dissimilarity tree and consequently genetically dissimilar when compared against the total population (fig. 3.7 and 3.8). The concordance between folk taxonomy and genetic relatedness is imperfect and specific for each folk specific taxon studied. The folk specific taxon *Llumchuy Waqachi* consists of a relatively large proportion (83.3%) of genetically similar cultivars, even though, at the folk varietal level, it consists of different entities like *Puka Llumchuy Waqachi* (red), *Rosada Llumchuy Waqachi* (pink), and *Muru Llumchuy Waqachi* (two-colored). Yet, the same does not hold true for the folk specific taxon *Ñata*, which is genetically diverse within the cultivar group. Accessions of this folk specific taxon, however, clustered relatively consistently at 62.5% with morphological descriptors, thus suggesting complementarity of both tools (SSR markers versus morphological descriptors). Accessions belonging to each of the folk specific taxa do not necessarily coincide neatly with formal taxonomic species classification (fig. 3.9).

Figure 3.7: Unweighted Neighbor Joining (NJ) dissimilarity tree (Jaccard's coefficient) for 190 accessions belonging to 9 cultivar groups and 2 individual cultivars based on 18 SSR primers



Gaspar	:	red (•)	*Peruanita*	:	water blue (•)
Ipillu	:	dark blue (•)	*Ritipa Sisan*	:	brown (•)
Llumchuy Waqachi	:	light green (•)	*Sirina*	:	turquoise (•)
Masa Waqachi	:	dark green (•)	*Suytu*	:	purple (•)
Ñata	:	orange (•)	*Wayru*	:	pink (•)
Pasña	:	grey (•)			

* The scale bar (0-0.1) represents the level (percentage) of dissimilarity

Figure 3.8: Level of coherent clustering of folk specifics and varietals with 18 SSR markers

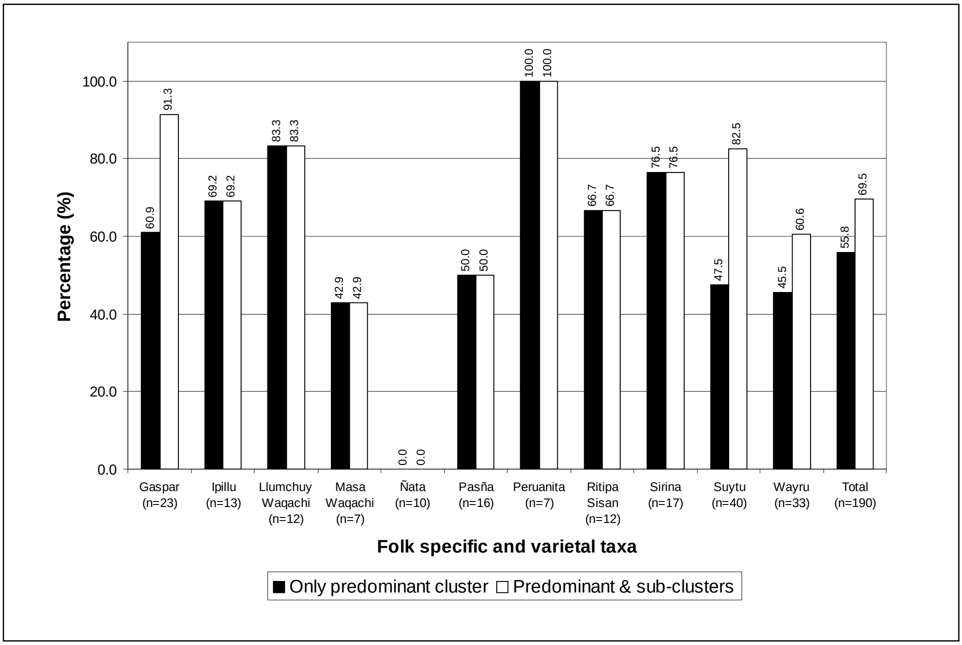
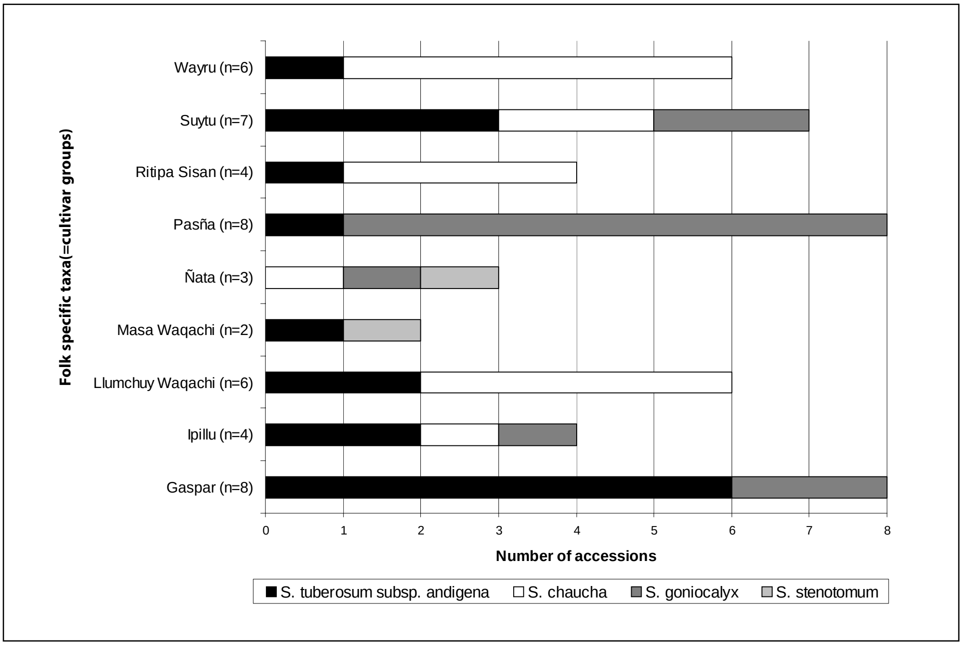


Figure 3.9: A total of 48 accessions from 9 folk specific taxa compared with formal species identification



3.3.2 Folk descriptors

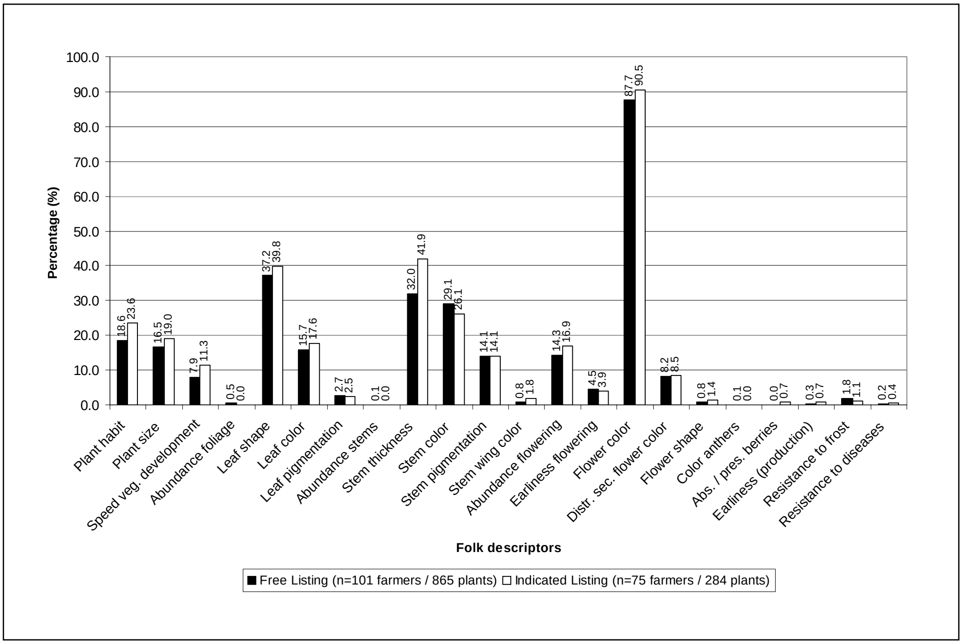
Informants used a total of 22 characters for the identification of cultivars at flowering stage without exposing tubers. Most characters (20) were based on direct observation of plant morphology and development: plant habit, plant size, speed of vegetative development, abundance of foliage, leaf shape, leaf color, leaf pigmentation, abundance of stems, stem thickness (diameter), stem color, stem pigmentation, stem wing color, abundance of flowering, earliness of flowering, distribution of secondary flower color, flower shape, color of the anthers, absence or presence of berries, and earliness (production). Most of these folk descriptors consisted of several character states, many in the Quechua language (table 3.6). Indirect characteristics used by farmers were resistance to frost and diseases (*Phytopthora infestans*); these were used only for identification when potato fields were actually affected by these pressures. The most frequently used folk descriptors for aboveground plant parts, in order of importance, are flower color, leaf shape, stem thickness (diameter), stem color, plant habit, plant size, leaf color, abundance of flowering, and stem pigmentation. Figure 3.10 shows the frequencies (relative importance) of descriptor use as a percentage of the total number of plants identified and characterized by informants, both for free listing (FL) and indicated listing (IL) exercises. Farmers manage a relatively large repertoire of descriptors for aboveground plant parts. Yet, certain descriptors such as flower shape, color of anthers, abundance of foliage and stems, stem wing shape, absence or presence of berries, and earliness of production were used only rarely by a small group of farmers.

Table 3.6: Sample of Quechua terms used for characterization

Plant parts	*alpuntu* (berry), *papa* (tuber), *raphi* (leaf), *sapi* (root), *killu* or *sisa* (tuber sprout), *sunqu* (tuber flesh), *tullu* (stem), *wayta* (flower),
Colors	*kulli* (purple), *puka* (red), *qamya kulli* (violet), *qamya puka* (pink), *qillu* (yellow), *qumir* (green), *uqi* (brown), *yana* (*black*), *yuraq* (*white*)
Color combinations	*allqa* (two-colored), *chiqchi* (pigmented, sparkling), *muru* (two-colored), tullpuyasqa (pigmented), qanrachasqa (spotted)
Stem thickness	*raku tullu* (thick stem), *tullu sapa* (thick stem), *yanu tullu* (thin stem), *qaqay tullu* or *qari tullu* (strong stem), *wañu wañu tullu* (weak stem)
Abundance stems	*achka tulluyuq* (abundant stems), *asya tulluyuq* (few stems)
Leaf shape	*qatun raphi* (big leaf), *taqsaya raphi* or *uchuya raphi* (small leaf)
Tuber shape	*suytu* (long), *ruyru* (round), *ñata* (compressed), *palta* (flat)
Eye depth	*gasper* (deep-eyed), *qawalla ñawiyuq* (shallow-eyed)
Eye size	*uchuya ñawi* (small-eyed), *ñawi sapa* or *qatun ñawi* (big-eyed)
Others	*manchaq* (susceptible; e.g. diseases), *qala* (smooth; e.g. tuber skin), *quyu* (green tuber), *sipu* (wrinkled; e.g. tuber skin), *waytaq anaqta* (late flowering)

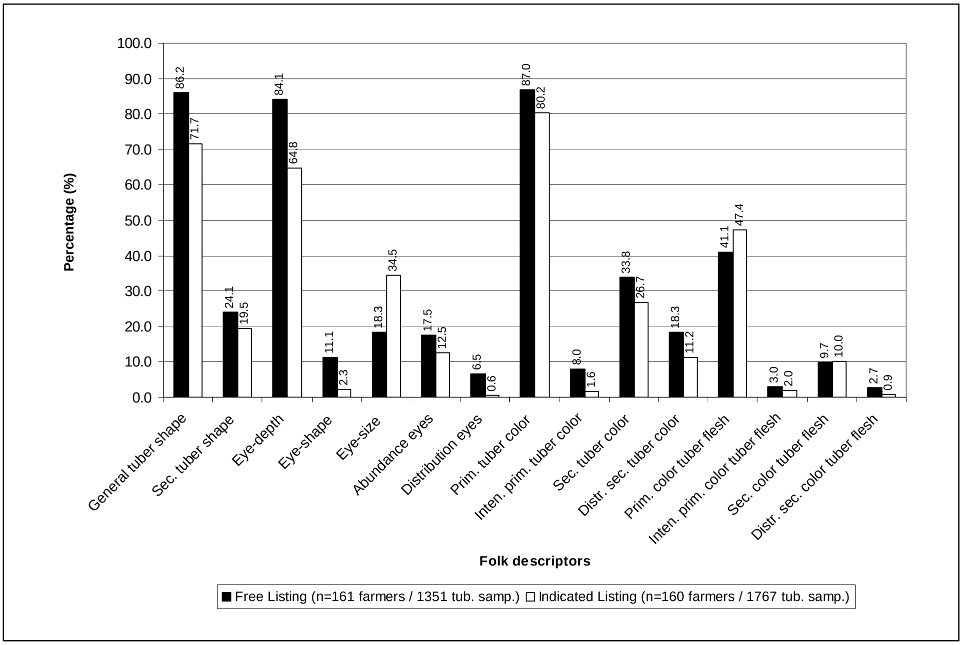
In addition farmers used a total of 15 morphological descriptors to identify cultivars based on tuber characteristics: general or primary tuber shape, secondary tuber shape, eye-depth, eye-shape, eye-size, abundance of eyes, distribution of eyes, primary tuber skin color, intensity of primary tuber skin color, secondary tuber skin color, distribution of secondary tuber color, primary color of tuber flesh, intensity of primary color of tuber flesh, secondary color of tuber flesh, and distribution of secondary color of tuber flesh. Again, mant of these general folk descriptors contained an inherent group of morphological keys, often expressed in Quechua (table 3.6). Figure 3.11 shows the frequencies (relative importance) of descriptor use as a percentage of the total number of tuber samples described by informants, both for the free listing (FL) and indicated listing (IL) exercises. The most frequently used folk descriptors for tubers, in order of importance, are primary tuber skin color, general tuber shape, eye depth, primary color of tuber flesh, secondary tuber skin color, eye size, and secondary tuber shape. The other folk descriptors are less frequently used and only by a relatively small group of farmers.

Figure 3.10: Frequencies of folk descriptor use for aboveground plant parts (FL[1] & IL[2])



[1] = free listing; [2] = indicated listing

Figure 3.11: Frequencies of folk descriptor use for tubers (FL[1] & IL[2])



[1] = free listing; [2] = indicated listing

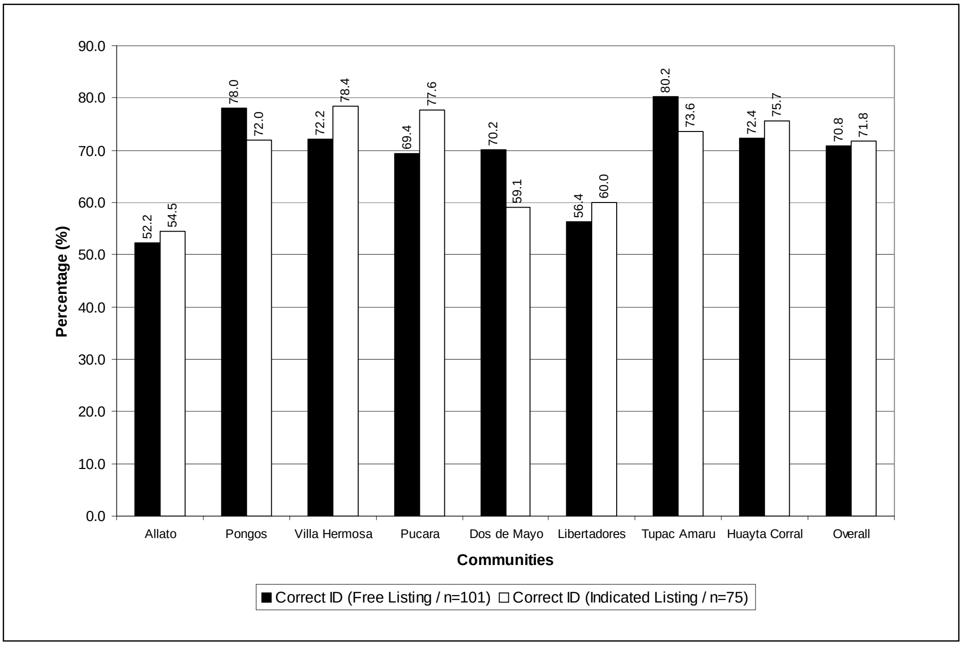
Farmers used a total average repertoire of 8.2 (FL) and 7.0 (IL) different folk descriptors in order to identify cultivars at flowering stage without exposing tubers, and an average of 2.9 (FL) and 3.1 (IL) plant descriptors in order to identify and name a single cultivar. The repertoires of different plant descriptors used varied between communities. Farmers from the community of Allato used a total average of 2.6 (FL+IL) different plant descriptors (minimum registered) while farmers from Tupac Amaru used a total average of 9.7 (FL+IL) different descriptors (maximum registered). Such differences also existed for the average number of folk descriptors used per individual plant sample. Farmers from Allato used an average of 1.4 folk descriptors (FL+IL) to identify and name each sample (minimum registered), while farmers from Tupac Amaru used an average of 3.8 folk descriptors (FL+IL) per sample (maximum registered).

Farmers used an average total repertoire of 9.1 (FL) and 9.4 (IL) different tuber descriptors. On average, informants used 4.2 (FL) and 3.5 (IL) folk descriptors per tuber sample (cultivar). Small differences existed between communities with a minimum average repertoire of 8.3 (FL+IL) different tuber descriptors being used in the community of Pucara and a maximum average repertoire of 12.2 (FL+IL) different tuber descriptors in Dos de Mayo. Farmers from the community of Pongos used an average of 3.2 (FL+IL) descriptors per tuber sample (minimum registered) while farmers in Dos de Mayo used an average of 5.0 (FL+IL) descriptors per tuber sample (maximum registered).

Generally, farmers were well able to identify specific cultivars through the use of aboveground plant parts only (without exposure of tubers). An overall average of 70.8% of the 865 plant samples used for free listing and 71.8% of the 284 samples used for indicated listing were identified correctly (fig. 3.12). Against expectations, correct identifications obtained with the indicated listing method were slightly higher in comparison with free listing. Notable differences exist between communities. Communities where farmers used a larger repertoire of different plant descriptors and a higher average number of folk descriptors per plant also obtained higher levels of correct cultivar identification.

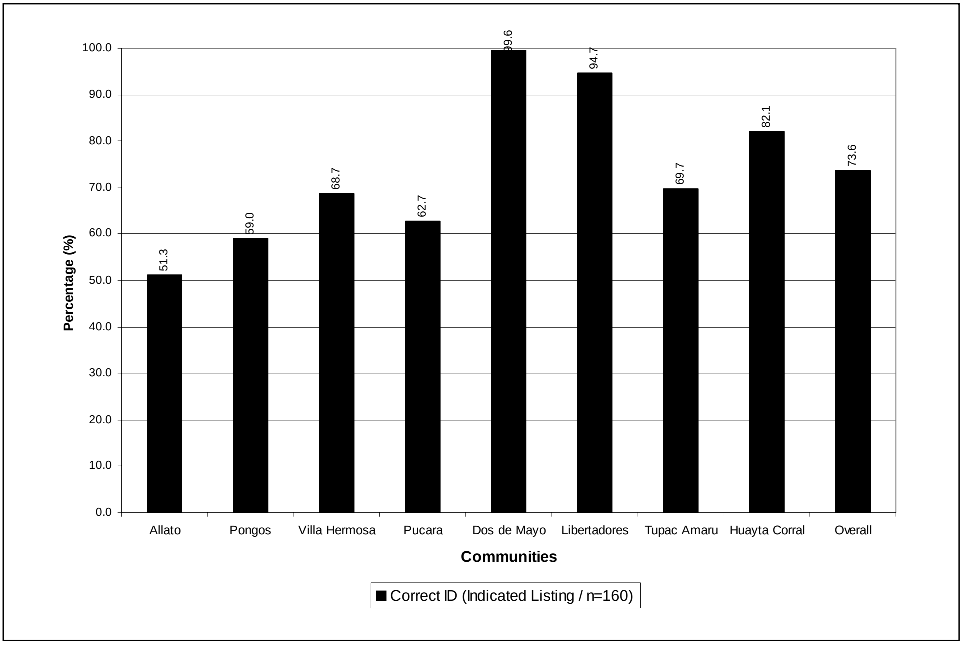
Farmers (n=160) also recognized most cultivars belonging to the fixed sample of 15 local cultivars (5 tubers per cultivar) used for the indicated listing method (fig. 3.13). A total average of 73.6% was recognized, yet considerable differences existed between communities. Communities where farmers used a larger repertoire of different tuber descriptors and higher average number of folk descriptors per tuber sample also obtained higher levels of recognition. No big differences for correct cultivar identification, either from plant or tuber samples, were found for gender or age. This suggests that basic descriptor knowledge is obtained at a young age and equally shared between men and women.

Figure 3.12: Percentage (%) of correct cultivar identifications by exposure to aboveground plant parts only (FL[1] & IL[2])



[1] = free listing; [2] = indicated listing

Figure 3.13: Percentage (%) of correct cultivar identification by exposure to tubers (IL[1])



[1] = indicated listing

3.3.3 Nomenclature

Consistency of cultivar naming practices

The 30 fixed native cultivar samples used for the regional nomenclature survey (n=193) resulted in the registration of 345 different names applied to the total sample. This is an average of 11.5 names (synonyms) per cultivar sample, a figure that, at first sight, pleads against the consistency of coherent naming practices. Figure 3.14 shows the total number of different vernacular names assigned to each native cultivar sample. There is considerable variability between samples, ranging from a minimum of three names for sample M31 to a maximum of 25 names for sample M60. Cultivar samples with few names such as M31 or M41 were recognized and named by a comparatively high number of informants. On the other hand, samples that received many names such as M60 or M52 were recognized and named by few informants, indicating that fewer farmers were familiar with these cultivars.

Figure 3.14: Total number of different vernacular names assigned to each cultivar sample

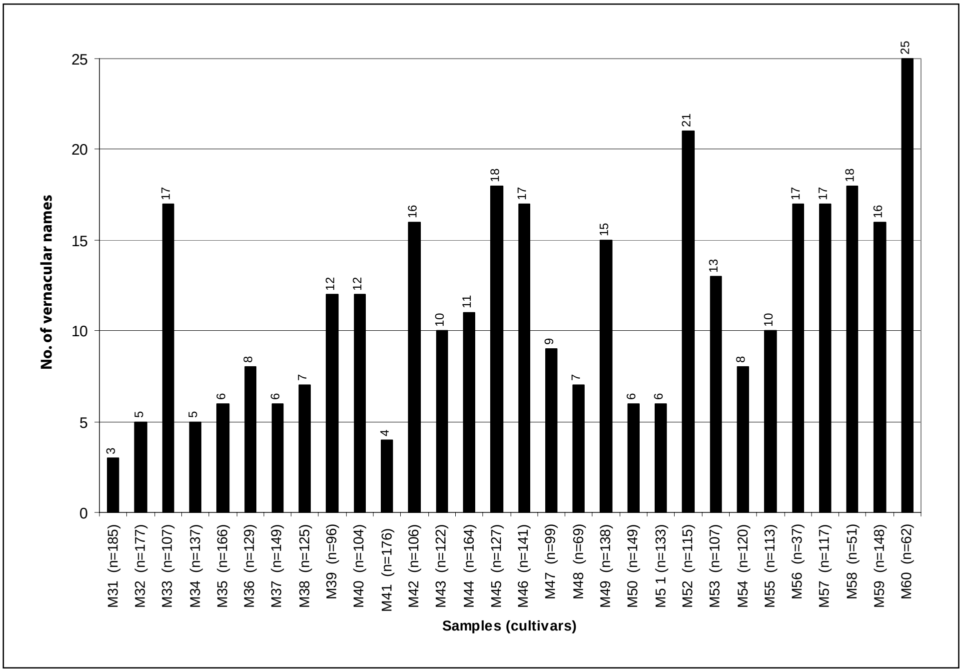


Figure 3.15 shows the relative importance of the predominant name assigned to each cultivar sample. It shows that, in general, samples with few names assigned by a high number of informants also tend to have a high regional predominance of a single name. By contrast, samples that received many names assigned by a limited number of informants tend to have low regional predominance of a single name. However, there are exceptions such as sample M55; it received 10 different names assigned by 113 farmers, but was regionally known by 70.8% of the informants as *Qanchillu*. Another contrasting exception is sample M37; it received only 6 names assigned by 149 farmers, yet its predominant name *Trajin Waqachi* was accounted for by only 46.3% of the informants. In general, cosmopolitan commercial and well-known cultivars receive consistent, regionally recognized names while scarce cultivars generally receive different names within and among communities.

Figure 3.15: Relative importance of the predominant name assigned to each cultivar sample

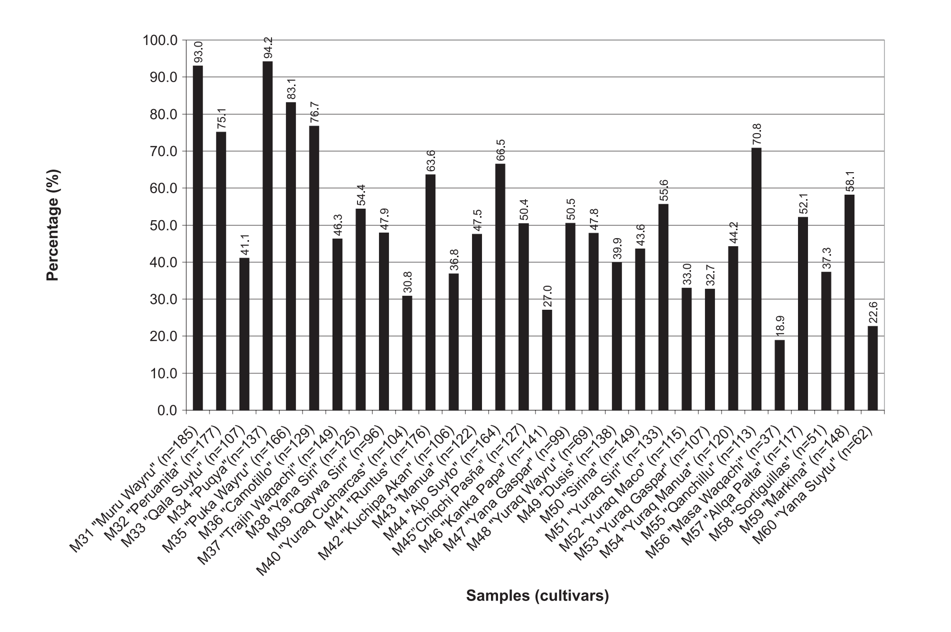
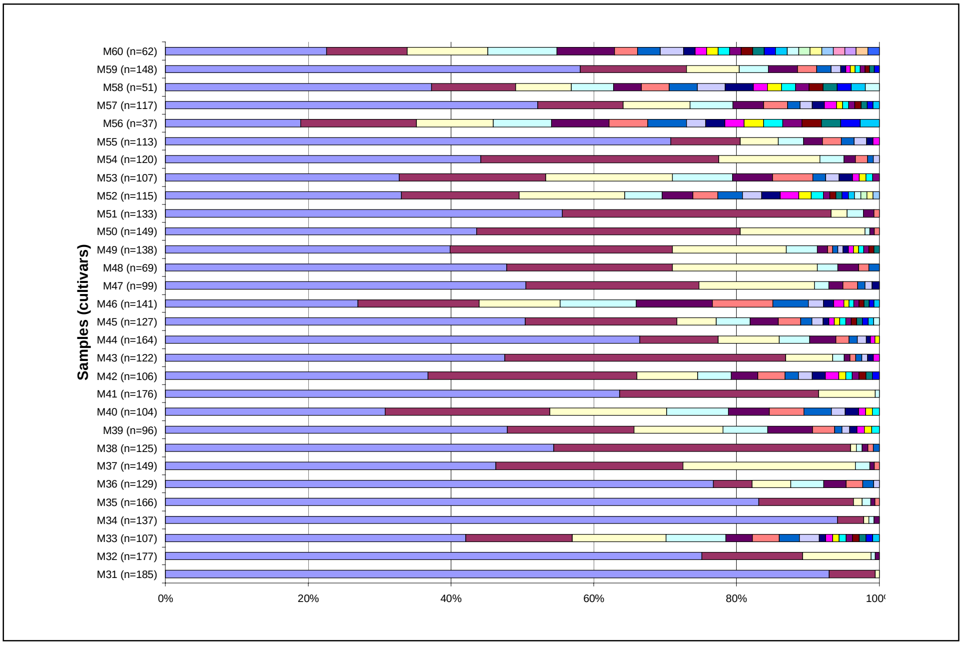


Figure 3.16 shows the relative importance of the total number of names assigned to each sample (cultivar) as a percentage of the total number of respondents having named each sample. Each color represents a different name, while the length of each color band indicates the relative importance or predominance of the name. Commercial native-floury cultivars are generally regionally well-known by a single predominant name; these include *Muru Wayru* (M31) and *Puka Wayru* (M35). Also common non-commercial native-floury cultivars such as *Puqya* (M34) are known by a single predominant name in all communities. Figure 3.16 shows that certain cultivar samples have a clear, single, predominant, regional name, while others samples such as M38, M43, M50, M51, and M54 have two predominant names. The former is mainly related to differences of cultivar naming between communities. Differences may be extremely small, such as in the case of sample M43, which is simply called *Manwa* in the communities of Allato (100%) and Dos de Mayo (91.3%), *Yana Manwa* in Villa Hermosa (95.2%) and Pucara (78.6), and *Yana Panwa* in Tupac Amaru (71.4%). Names can also be quite different, such as in the case of the well-known cultivar sample M32; it is known in most communitiess as *Peruanita* (63.6 - 100%) and only in the community of Allato predominantly as *Limeña* (92.6%).

Some cultivars are consistently named in some communities while inconsistently named in others. This is the case for sample M46, which received the predominant name *Kanka Papa* in Dos de Mayo (72.7%) and *Yuraq Ipillu* in Villa Hermosa (59.1%), while receiving 10 inconsistent names in the community of Huayta Corral. The differences probably depend on the relative abundance of a specific cultivar within a particular community. Regionally scarce cultivars such as represented by sample M60 receive many names, few of which were consistently applied within communities. The use of homonyms is common for similar morphotypes (folk varietal taxa) belonging to the same cultivar group (folk specific taxon).

Figure 3.16: The relative regional importance of the total number of names assigned to each sample



Ethnolinguistic structure of cultivar names

A basic and quantitative linguistic analysis of language, structure, and meaning was conducted for non-duplicate names (n=751) registered in Huancavelica. Most farmers, especially male inhabitants, are bilingual (Quechua and Spanish) and this is reflected in the languages inherent to potato nomenclature. A total of 53.9% of names analyzed were pure Quechua, 27.3% a mix of Quechua and Spanish, 17.7% pure Spanish, 0.7% a mix of Aymara and Spanish, 0.3% a mix of Quechua and Aymara, and only 0.1% pure Aymara. The scarce use of Aymara words is associated with cultivars that have their origin in Southern Peru or Bolivia and have maintained their cosmopolitan names. An example is the cultivar group *Imilla*, meaning "girl" in the Aymara language.

The basic structure of most cultivar names consist of two-worded names (68.3%) followed by three-worded names (16.8%). Single-worded cultivar names represented 14.2% of the total sample analyzed, while four-worded names are rare (0.7%). As noted early on by Hawkes (1947) and La Barre (1947), a considerable proportion of cultivar names consist of a noun and one or two qualifying adjectives. This is most obvious in names of cultivars from Huancavelica such as *Puka Pasña* (red girl), *Muru Wayru* (two-colored *Wayru*), *Chiqchi Runtu* (sparkling egg), or *Qillu Qala Maqta* (yellow naked youngster). The noun is generally the word that refers to the folk specific taxon (cultivar group), while the qualifying adjective(s) specifies the folk varietal taxon (specific cultivar). In the case of the abundant metaphorical references to animal body parts, such as *Wakapa Qallun* (cow's tongue), *Wachwapa Qallun* (goose's tongue), *Pumapa Makin* (puma's paw), and *Misipa Makin* (cat's paw), it is generally the body parts that represent a folk specific taxon (cultivar group), e.g. *qallun* (tongue) or *makin* (paw), and the animal species, e.g. *wakapa* (cow's), *wachwapa* (goose's), *pumapa* (puma's) or *misipa* (cat's), that constitute the qualifying adjective.

Other cases of cultivar nomenclature require a minimal level of knowledge of the total population structure in order to be able to define the noun(s) and qualifying adjective(s). Participant observation and discussion with farmers helped to clarify many of the difficult cases, such as two-worded metaphorical names for a folk specific taxon. These are an exception to the general rule that the noun is single-worded and include common cultivar groups as *Llumchuy Waqachi* (make daughter-in-law cry) and *Ritipa Sisan* (snow glint). In these cases the folk varietal taxa (specific cultivars) often consist of three-worded names, e.g. *Yana Llumchuy Waqachi* (black make daughter-in-law cry) or *Uqi Ritipa Sisan* (brown snow glint). Insights such as these were used for a detailed analysis of cultivar names, considering the word(s) that compose primary names (folk specifics and often nouns) and secondary names (adjectives).

Of all 751 primary names (nouns) analyzed, 74.6% had a specific known meaning while 25.4% did not have a specific known meaning. Names without a specific known meaning mostly included well-known cultivar group names such as *Siri*, *Waña*[17] , *Manwa*, or *Wayru*. The actual meanings of these names have become lost or, in any case, are not remembered by farmers in Huancavelica. Primary names with a specific known meaning (n=560) are extremely diverse and subdivided into those names with a direct (non-metaphorical) meaning and those with an indirect (metaphorical) meaning. Indirect or metaphorical meanings of primary cultivar names are most common, representing 68.4% of all names with a specific known meaning. About a third, or 31.6%, of primary cultivar names with a specific known meaning actually had a direct or non-metaphorical meaning. Table 3.7 shows the basic categories that define the meaning of primary cultivar names with a direct (non-metaphorical) specific known meaning. Direct references to tuber shape and supposed origin compose the most important direct naming categories.

Table 3.7: Categories of primary cultivar names with direct (non-metaphorical) known meanings (n=177)

Relative Importance		Category	Components		Exemplary / illustrative name(s)
Rank	%		No.	Sample types	
1	51.7	Tuber shape	5	long, deep-eyed, flat, compressed	'Puka Palta'
2	31.7	Origin	3	nationality, region or place	'Peruanita', 'Tarmeña'
3	8.8	Tuber parts	3	eyes, flesh, sprouts	'Azul Sisa'
4	2.9	Plant parts	2	flower, stem	'Puka Wayta'
5	2.4	Tuber color	3	yellow, black, orange	'Amarilla', 'Naranjillo'
5	2.4	Tub. color comb.	1	two-colored	'Murunki'

The naming categories for indirect (metaphorical) primary cultivar names with specific known meanings are tuber shape, tuber color (combination), gender, state of being, and others. Reference to tuber shape constitutes the main naming category for indirect (metaphorical) primary cultivar names with a specific known meaning, representing 79.5% of all cases analyzed (table 3.8). The diversity of metaphorical naming subjects for tuber shape is abundant and therefore this category is subdivided into subcategories and components. The category "tuber shape" (n=289) consists of the following subcategories: body parts (24.8%), objects (23.0%), plants and crops (18.4%), persons (14.5%), animals (10.0%), and others (9.3%). Each of these subcategories contains numerous components commonly used for primary cultivar names (nouns), including *runtus* (testicles), *uman* (head), *ruyru* (kidney), *qaywa* (weaving tool), *tuqra*

[17] Gose (1994, p.126) translates *waña* as "dead" or "dry". Farmers in Huancavelica, however, assign no meaning to the word *waña* and just consider it a name for a cultivar group.

(supplement for chewing coca leafs), *rumi* (stone), *uchu* (pepper), *rosas* (roses), *maqta* (male youngster), *ñusta* (female youngster), *chaywa* (fish), *sirina* (mermaid), and *llumchuy waqachi*[18] (make daughter-in-law cry) among others.

Table 3.8: Categories of primary cultivar names with indirect (metaphorical) known meanings (n=383)

Relative Importance		Category	Subcategory		Components	
Rank	%		No.	Sample types	No.	Sample types
1	79.5	Tuber shape	>6	body parts	>22	testicles, paw, tongue, etc.
				animals	>13	bull, cricket, snake, etc.
				plants & crops	>15	rose, sweet potato, etc.
				persons	7	girl, youngster, widow, etc.
				objects	>28	skirt, dress, tool, egg, etc.
				others	>5	mermaid, etc.
3	4.9	Tub. color (comb.)			>8	flag, rainbow, etc.
4	1.9	Gender			2	male, female
5	0.5	State of being			2	bursting, pregnant
2	13.2	Others			>10	floury, roasted, etc.

A total of 630 cultivar names or 83.9% of the total sample were used for analysis of secondary cultivars names (qualifying adjectives; indicators for folk varietal taxa). Single-worded names and two-worded names representing a primary name were excluded. A majority of 94.4% (n=620) of the cultivar names considered had a specific known meaning. In turn, 71.5% of the subsample with a specific known meaning consisted of direct or non-metaphorical names (n=443). In contract to primary names, only 28.5% of the secondary cultivar names were indirect or metaphorical (n=177).

Table 3.9 shows the basic categories that define the meaning of secondary cultivar names with a direct (non-metaphorical) specific known meaning. Direct references to tuber color and tuber color combinations compose the most important direct naming categories for secondary cultivar names, representing 82.5% of the subsample analyzed. The naming categories for indirect (metaphorical) secondary cultivar names with specific known meanings are diverse (table 3.10). Animals constituted the most important category with abundant components referring to specific animal species that constitute secondary cultivar names. Most of these are linked to primary names referring to body parts.

[18] This name refers to a cultivar group with very deep-eyed tubers that were apparently used in the past to test the ability of the daughters-in-law. The test consisted in peeling the potatoes, an impossible job that would make the daughter-in-law cry.

Table 3.9: Categories of secondary cultivar names with direct (non-metaphorical) known meanings (n=443)

Relative Importance		Category	Components		Exemplary names
Rank	%		No.	Sample types	
1	69.5	Tuber color	11	purple, white, black, brown, pink	'Yuraq Pasña'
2	13.0	Tub. color comb.	2	two-colored (*muru*, *allqa*)	'Muru Wayru'
3	6.7	Tuber shape	4	long, round, flat, compressed	'Tumbay Larga'
4	5.9	Potato (name)	1	potato (*papa*)	'Pasña Papa'
5	2.5	Tuber size	2	small (*pichi*), big (*qatun*)	'Pichi Runtu'
6	2.1	Origin	2	nationality, region or place	'Manwa Peruana'
7	0.3	Commonness	1	common	'Maco Común'

Table 3.10: Categories of secondary cultivar names with indirect (metaphorical) known meanings (n=177)

Relative Importance		Category	Components		Exemplary names
Rank	%		No.	Sample types	
1	27.2	Animals	>19	puma, eagle, lama, pig, donkey	'Ankapa Sillun'
3	15.4	Tuber eyes	7	big-eyed, blood-eyed, blue-eyed	'Yawar Ñawi Pasña'
4	15.0	Tub. color comb.	>7	decorated, rainbow, football team	'Killi Wara'
5	6.6	Tuber skin	1	smooth or naked (*qala*)	'Qala Wawa'
6	5.7	Gender	2	male (*urqu*), female (*china*)	'Urqu Tumbay'
7	4.8	TS Plant & crops	>5	cucumber, oca, sweet potato	'Pepino Suytu'
8	2.2	Tuber flesh	4	hart, black-hart, purple-hart	'Yana Sunqu Dusis'
9	1.7	TS Object	2	tools (*qaywa*)	'Qaywa Siri'
2	21.4	Other	>14	roasted, salted, floury, old lady's	'Payapa Ankun'

3.4 Discussion and conclusions

Potato folk taxonomy in Huancavelica, Peru, recognized at least five ranks: life-form (*Yura*), intermediate (*Papa*), generic (*Araq Papa*, *Papa Tarpuy*, *Atoq Papa*), specific (cultivar groups), and varietal (cultivars). Taxa within the folk generic taxon *Papa Tarpuy* (cultivated potato), at the folk specific and varietal rank, are particularly abundant. This is characteristic for domesticated and cultivated plants when compared to wild flora, which is generally reported to have most folk taxa at the generic rank (Berlin, 1992). The folk generic taxa *Araq Papa* (semi-wild/consumed) and *Atoq Papa* (wild/not consumed) do lack folk specific taxa and only have a limited number of folk varietal taxa that are recognized by relatively few farmers. The main differentiating factor between the three folk generic taxa is based on a combination of relative state of wildness and aptitude for consumption.

In contrast to other reports on Andean potato folk taxonomy (Brush, 1980, 2004; Zimmerer, 1996), use criteria and agroecology did not constitute main differentiating factors. Use and agroecology constitute different systems of categorization for specific purposes that, in the case of Huancavelica, cannot necessarily be accommodated under the umbrella of folk taxonomy. Yet, farmers from the research communities do differentiate well between categorization for the purpose of taxonomic relatedness (communication) and for the purpose of utilization (use categories) or environmental fit (cultivation zones). The folk taxonomical system is used for regional and trans-generational communication. Classifications based on use or agroecology serve a different purpose.

Although native-bitter folk specifics (cultivar groups such as *Siri*, *Waña*, and *Qanchillu*) were considered to be more closely related among each other when compared with their numerous non-bitter (native-floury) equivalents, bitterness did not offer a sufficient base for informants to consider additional specific ranks or taxa. This is partially related to the fact that native-bitter cultivar groups and specific cultivars are a very small portion of the total diversity classified by farmers as *Papa Tarpuy*. Farmers certainly recognize groups of potatoes that are used for boiling, freeze-drying, soups, barter, sales, and medicine. For example, farmers in Huancavelica do differentiate between floury ("*machqa machqa*"; good for boiling) and watery ("*luqlu*"; good for soups) cultivars for utilitarian purposes. However, these characteristics do not determine the folk taxonomic system *perse*. Several primary use categories, e.g. boiling, soups, and sales, may apply to a single cultivar making it difficult for farmers to make use-based categorization rigid for the purpose of taxonomical classification and communication. Native-bitter cultivars are not only used for freeze-drying, but also for soups (fresh and freeze-died). *Yungay*, an improved cultivar commonly used for boiling and frying, has also become a favorite *chuño* cultivar in Huancavelica. Therefore use categories of Andean potatoes are far from absolute and constitute a specific classification system for utilitarian purposes. Similarly, agroecology is a complementary criterion for categorization and is not strictly used for folk taxonomy.

Folk varietal taxa cluster relatively well when using formal morphological descriptors: *Peruanita* (87.5%) and *Sirina* (73.3%). Yet, folk specific taxa do not cluster well with the same set of environmentally stable descriptors when levels of consistency are based upon a single predominant cluster without considering clear subclusters. A folk specific taxon is made up of small subpopulations that are morphologically distinct, yet share certain key characteristics that farmers use to group them. A basic ethnolinguistic analysis showed that folk specific taxa are mainly classified by tuber shape, while folk varietal taxa are additionally differentiated by tuber color and tuber color combinations. Yet, a similarity analysis based on tuber morphology did not show higher levels of coherent clustering when compared with environmentally stable descriptors. This suggests that folk specific taxa have overlapping tuber morphologies and that very particular combinations of characters define a folk taxonomic entity.

The use of highly polymorphic microsatellite markers (SSR) coherently grouped folk varietal taxa: *Peruanita* (100%) and *Sirina* (76.5%). Certain folk specific taxa, such as the *Llumchuy Waqachi* cultivar group, also clustered relatively consistently (83.3%). Yet, while some folk specific taxa show a moderate concordance for molecular relatedness, there are considerable exceptions. Folk specific taxa such as *Pasña* showed intermediate to low levels of coherent clustering (50.0%), while yet others, such as *Ñata*, did not cluster at all (0%) and had individual accessions scattered along the dissimilarity tree. The level of coherent clustering for the whole population was moderate with 55.8% for single predominant clusters and 69.5% for predominant clusters and subclusters. So, the relation between folk specific taxa and genetic relatedness determined by SSR markers is certainly not perfect and the specific level of coherent clustering depends on the particular folk specific taxon considered. This contrasts with findings from Quiros *et al.* (1990), reporting a general high degree of correspondence between farmer identification (names) and electrophoretic phenotypes. The present study, however, does confirm the finding reported by Quiros *et al.* (1990) that phenotypes with the same name can be genetically different, possibly leading to a slight underestimation of genetic variability maintained by some farmers. This case is exemplified by the folk varietal taxon (cultivar) *Sirina* with 23.5% of accessions genetically dissimilar from the single predominant cluster (76.5% of accessions). Zimmerer and Douches (1991) also allude to this when they conclude that major allelic variation is contained within cultivar populations. Indeed, our results confirm that genetic diversity within a folk specific taxon (cultivar group) can be considerable.

Folk varietal taxa (cultivars) belonging to the same farmer-recognized folk specific taxon do not necessarily belong to the same formal taxonomic species. Depending on the folk specific taxon, it may be composed of folk varietals belonging to two or three formal species. This is partially a consequence of morphological similarity as even for trained potato taxonomists and curators it is difficult to separate formal species based on morphology only. Yet, this situation is not assigned to a dynamic open state of the genepool as sustained by Quiros *et al.* (1992). Andean farmers only very rarely consciously use and manage botanical seed and even though spontaneous hybridization between species and cultivars is common, the resulting progenies are rarely incorporated into farmers' seed stocks. This is particularly true for high-altitude potato cropping systems where rotation practices (grain crops after potato) and climate (frost in June and July) restrict the emergence of new genotypes from botanical seed.

Farmers used a total of 22 folk descriptors for recognizing and naming a cultivar based on plant characteristics and without exposing tubers. In addition farmers used 15 folk descriptors to identify and name cultivars based on tuber characteristics. The total set of descriptors used by farmers is based on 35 morphological characters and 2 resistance traits. Some of the morphological farmer descriptors coincide while other differ from formal descriptors (see Gómez, 2000; Huaman and Gómez, 1994). Frequently used farmer descriptors which are not formal descriptors include leaf shape, stem thickness, plant size, leaf color, and tuber eye size; each of which contains several character states with inherent Quechua terminology.

Contrary to earlier reports (Gade, 1975, p.205; Hawkes, 1947, p.222), farmers were generally well able to recognize and name specific cultivars based on flowering plants and without exposing tubers with overall correct identification rates of 70.8% for free listing and 71.8% for indicated listing at flowering stage. Farmers from the various communities managed different total repertoires and average numbers of descriptors for the identification of a single cultivar sample, indicating that knowledge varies among communities. Communities where farmers used a larger total repertoire and average number of descriptors per sample, both for plants and tubers, also obtained higher ratios of correct identification. This suggests that farmers from particular communities are generally more knowledgeable compared to others. This, in turn, may be a consequence of local tradition or even the relative levels of infraspecific diversity maintained within communities. No differences for correct cultivar identification, either from plant or tuber samples, were found for gender or age. This suggests that basic descriptor knowledge is generally obtained at a young age and equally shared among men and women.

A regional survey with 30 fixed cultivar samples identified and named by 193 informants showed differences in the consistency of naming practices for each of the cultivars. Well-known commercial cultivars and regionally important cultivars were identified consistently with a predominant regional name. Other cultivars were consistently named within communities while receiving different names between communities. Scarce cultivars were named by few informants and showed higher ratios of inconsistency, both within and between communities. So the consistency of naming practices depends to a large extent on the relative commonness or abundance of a particular cultivar. This implies that scarce cultivars of interest for conservation efforts will be difficult to identify via nomenclatural surveys and therefore additional complementary tools are needed. The use of homonyms is common for similar morphotypes (folk varietal taxa) belonging to the same cultivar group (folk specific taxon).

The basic ethnolinguistic analysis of 751 non-duplicate cultivar names unraveled a predominant structure of naming categories applied to direct and metaphorical primary (noun) and secondary (adjective) cultivar names. Two-word and three-word cultivar names were predominant. Primary cultivar names (nouns) generally refer to a folk specific taxon, while the secondary name specifies the folk varietal taxon. Metaphorical primary cultivar names are abundantly used; they represented 68.4% of the entire sample of primary names with a specific known meaning. In general, tuber shape constitutes the principal naming category for direct and indirect primary cultivar names. A total of 71.5% of the secondary cultivar names with a specific known meaning were direct or non-metaphorical. These secondary cultivar names predominantly provide direct (non-metaphorical) reference to tuber color or color combination. Nevertheless, there are exceptions to these general rules. While many old cultivar names are still maintained, there is evidence to suggest that nomenclature is highly dynamic. Some cultivar names refer to animals, such as cows, pigs, and cats, which were introduced after the arrival of the Spanish conquistadors five centuries ago. References to Peruvian football teams, e.g. *Alianza* (cultivar name is *Suytu Alianza*, old name is *Suytu Amaru*), suggest that new names are continuously invented and incorporated.

The selected conclusions outlined above offer relevant lessons for the communication interface between research and development- (R&D) oriented conservation efforts and farmer-driven *in-situ* conservation. First, there is a difference of scale between folk and formal taxonomy. While formal taxonomy predominantly focuses on botanical species, folk taxonomy of the cultivated potato concentrates on infraspecific diversity with the highest number of taxa found within the folk specific (cultivar groups) and folk varietal (cultivars) ranks. As shown here, moderate overlap between the two systems exists. Yet, the overlap is far from perfect and different for each folk taxonomical entity. Therefore, formal and folk taxonomy should be treated as complementary and R&D-orientated conservation practices should preferably take both systems into account. Second, farmers' ability to classify their cultivar stocks with folk descriptors should not be underestimated. Farmers manage a sizeable repertoire of folk descriptors, some of which coincide with formal descriptor lists. An effort should be made to incorporate folk descriptors into the future evaluation of infraspecific diversity in order to validate these additional criteria of classification. Third, cultivar nomenclature is based on a consistent set of linguistic categories. Yet, while naming practices between and within communitiess are relatively consistent for common cultivars, they are generally not coherent for rare cultivars of interest for conservation efforts. Therefore nomenclatural surveys and cultivar names cannot be used as a single indicator for diversity, but can help to determine the relative abundance of cultivars and prioritize conservation efforts. More generally, indigenous biosystematics of Andean potatoes, and its inherent subsystems of folk taxonomy, folk descriptors and nomenclature, constitutes an important complex of evolving, context-specific, and dynamic indigenous knowledge that is highly relevant for conservation efforts.

4. Annual spatial management of potato diversity in Peru's central Andes[1]

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Key words: potato, genetic diversity, Huancavelica, cropping calendars, field scattering, GxE interaction

Abstract

Farmers in the department of Huancavelica - Peru manage a large repertoire of improved, native-floury and native-bitter potato cultivars belonging to six botanical species. This genetic diversity is annually cultivated in dispersed fields covering several altitude-differentiated agroecologies. Annual spatial management consists of cropping and labor calendars, field scattering practices, and genotype by environmental management. This article investigates these three dimensions of potato management. Complementary methods of research were applied: structured surveys, a participatory "field scattering" sampling and cartography exercise, and a genotype by environmental (GxE) experiment along an altitudinal transect.

The annual distribution of tasks and labor is primarily an adaptation to the rain-fed character and climate extremes of high-altitude agriculture while different footplough based tillage systems allow farmers to efficiently manage scarce labor availability for soil preparation. Native-floury, native-bitter and improved potato cultivars show considerable overlap concerning their altitudinal distribution patterns. The notion that these cultivar categories occupy separate production spaces (so-called "altitudinal belts") is rejected. Farmers annually install numerous scattered potato fields (4.9 ± 2.9) with different cultivar compositions. Field scattering is based on a combined logic which results in patchy distribution patterns of potato genetic diversity across the agricultural landscape. Andean farmers manage high levels of genetic diversity, but not because of fine-grained cultivar adaptations. Most cultivars are versatile. Rather, farmers consciously manage combined tolerance and resistance traits according to perceived level of risks in specific agroecologies.

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4.1 Introduction

4.1.1 Agroecosystems

Agrobiodiversity of the potato in its center of origin, when conceptualized at different scales, consists of agroecological, species and genetic diversity. The latter two are comprised of specific genotypes which at the same time represent species and genetic diversity. Yet, agroecology, when perceived as the distribution of genotypes within the agricultural landscape, is typically a consequence of multiple factors. Relatively little is known about the yearly distribution of diverse potato cultivars within agroecosystems and how farmers manage environmental interaction. Andean agroecosystems are both diverse and extreme in the sense that they are the highest in the world, prone to weather extremes such as frost and hail, subject to private and communal decision making, subdivided by fragmentized and relatively small holdings, and interconnected by an overall management regime that provides individual households with access to multiple production zones. It is within this complex spatial and social environment that Andean farmers annually manage high levels of potato genetic diversity. Annual spatial management of the potato is subject to the basic rhythms inherent to cropping and labor calendars, field scattering practices, and farmer management of cultivars, environments and the interaction among them.

4.1.2 Cropping and labor calendars

Potato cropping cycles in the central Andean highlands are predominantly rain-dependent. The basic rhythm of annual events have seemingly changed little when comparing contemporary cropping cycles with those described by Guamán Poma de Ayala (c. 1583-1613). The central and southern Peruvian highlands have two common cropping calendars. The more humid northern and eastern Peruvian Andes and irrigated valley bottoms often have additional calendars. Characterization of cropping and labor calendars allows for better knowledge of labor distribution patterns and peaks, gender divisions and variations through specific management options. The latter typically includes different tillage systems based on the use of the Andean footplough (*chakitaklla*[2]) which are commonly applied to potato cropping (Cook, 1918; Gade and Rios, 1972, 1976; Rivero Luque, 1990, 2005). Though traditional footplough-based tillage systems have been interpreted from an adaptation perspective for managing different types of slopes, soils and moisture regimes (Bourliaud *et al.*, 1988), little attention has been given to their role in distributing demand for labor. Andean smallholder agriculture is characterized by the participation of both man and women (Deere and León de Leal, 1985; Weismantel, 1988). Yet, gender based labor divisions for Andean potato cropping systems have been scarcely documented.

4.1.3 Field scattering

Field scattering is common to the Andes and farmers often manage space by planting several dispersed potato fields rather than a single consolidated one. Scattered and fragmentized land holding as extreme as a few rows per family resulting from traditional inheritance rights and ever growing rural population sizes have been reported throughout the southern Peruvian Andes (Alfaro *et al.*, 1997; Bergman and Stroud Kusner, 2000). Although field scattering may reduce the risk of crop failure (Camino, 1992; Goland, 1993; Morlon, 1996a), there is no unequivocal empirical evidence to show that it is actually undertaken with this express purpose (Campbell and Godoy, 1986, p. 326). It has also been suggested that farmers purposefully plant scattered fields because native cultivars are narrowly adapted to tailored niches (Bernbaum, 1999; Soleri and Smith, 1999).

[2] *Chakitaklla*= Andean footplough; a tool of pre-Columbian origin developed for turning and breaking the soil and still commonly used throughout the Andes.

Indeed, field scattering may be based on a combined rationale including factors such as differential management of fields for distinct production objectives (consumption, sales, processing), risk management, fragmentized property regimes, or narrow genotype by environmental (GxE) adaptation of native cultivars. From a crop conservationist perspective a better understanding of field scattering may provide insights into the spatial distribution of genetic diversity.

4.1.4 Spatial patterning of species and cultivars

Cultivated potato species are characterized by a globally uneven geospatial distribution pattern (table 4.1). *S. tuberosum* subsp. *tuberosum* is the only (sub)species with large cultivated areas outside of South-America. *S. tuberosum* subsp. *andigena*, with few exceptions (see Barandalla *et al.*, 2006; Harris and Niha, 1999; Ríos *et al.*, 2007) is mainly cultivated in the Andean region, as are *S. curtilobum*, *S. chaucha*, *S. juzepczukii*, *S. stenotomum*, *S. goniocalyx*, *S. phureja* and *S. ajanhuiri*. Some of the Peruvian departments have most of the cultivated potato species within their territory; such is the case for Huancavelica where all species except *S. ajanhuiri* have been reported (CIP, 2006; Ochoa, 2003). Little is known about the spatial patterning of genotypes at a finer scale, particularly how diverse potato cultivars are distributed within the agricultural landscape. Different cultivar categories are generally considered to be separated by altitude with native-floury[3], native-bitter[4] and improved cultivars[5] reportedly occupying different production spaces. However, it is not clear whether this is true for contemporary potato production spaces in the central Peruvian Andes as socioeconomic change has the potential to redistribute the spatial arrangements of cultivar groups. Zimmerer (1998) observed that native cultivars had largely disappeared from the low-altitude cropping areas of the Paucartambo province in Southern Peru. Indeed, the gradual replacement of native potato populations is likely to have been a common process throughout the Peruvian Andes after the initial successful dissemination of improved cultivars about five decades ago.

A zone model is commonly used to account for the spatial and environmental organization of Andean land use (Zimmerer, 1999). Several ecological classifications for the Andean environment have been proposed (e.g. Holdridge, 1967; Pulgar Vidal, 1996; Tapia, 1996; Tosi, 1960; Troll, 1968). High levels of infraspecific diversity are often considered to be linked to the existence of diverse microhabitats and the tailored local adaptation of cultivars to specific niches (Bernbaum, 1999; Harlan, 1975). A niche is the multidimensional space that is unique and exclusive to a species or cultivar (Brush, 2004). Zimmerer (1998, 1999) has questioned the zone and niche models by drawing attention to a more flexible reality with a high degree of overlap and patchiness between farm spaces, versatile ecological adaptation and coarse-grained distribution patterns of potato allowing for cultivation across heterogeneous environments. The relation between potato cultivar diversity and altitude differentiated cropping environments in the central Peruvian Andes needs clarification. Are native cultivars indeed narrowly adapted to specific agroecological niches or is their spatial distribution the result of a different logic?

[3] Native-floury cultivars commonly belong to *S. tuberosum* subsp. *andigena*, *S. chaucha*, *S. stenotomum* and *S. goniocalyx*.

[4] Native-bitter cultivars commonly belong to *S. juzepczukii*, *S. ajanhuiri* and *S. curtilobum*.

[5] Improved cultivars commonly have *S. tuberosum* subsp. *tuberosum* within their pedigree.

Table 4.1: The general geographic distribution of cultivated potato species

Species[1]	Ploidy	Infrasp. diversity[2]	Areal range[3]	Geographic distribution Countries[3]	Regions[3]	Altitude[a] (m)
S. curtilobum	$2n=5x=60$	Low (6)	Medium	PER, BOL	Central Peru to Bolivia	3,800-4,050
S. tuberosum subsp. *andigena*	$2n=4x=48$	High (2864)	Ample	VEN, COL,ECU, PER, BOL, ARG	Whole Andes	1,950-4,050
S. tuberosum subsp. *tuberosum*	$2n=4x=48$	Med. (147)	Worldwide	Multiple	Multiple	0-3,600
S. chaucha	$2n=3x=36$	Med. (163)	Medium	PER, BOL	Central Peru to Bolivia	3,300-4,000
S. juzepczukii	$2n=3x=36$	Low (36)	Medium	PER, BOL	Central Peru to Bolivia	3,800-4,000
S. stenotomum	$2n=2x=24$	Med. (267)	Medium	PER, BOL	Central Peru to Bolivia	3,200-4,000
S. goniocalyx	$2n=2x=24$	Low (87)	Medium	PER	Central-Southern Peru	3,100-4,000
S. phureja	$2n=2x=24$	Med. (196)	Medium	COL, ECU, PER	Eastern Andes and inter-Andean valleys	1,800-3,400
S. ajanhuiri	$2n=2x=24$	Low (14)	Limited	PER, BOL	Altiplano Peru and Bolivia	3,800-4,000

[1] = taxonomy based on CIP genebank system; cultivars categories: a. improved (*S. tuberosum* subsp. *tuberosum*), b. native-bitter (*S. juzepczukii*, *S. curtilobum*, *S. ajanhuiri*), c. native-floury (*S. tuberosum* subsp. *andigena*, *S. chaucha*, *S. goniocalyx*, *S. stenotomum*, *S. phureja*); [2] = numbers between brackets represent the number of accessions held at CIP; [3] = based on Hawkes (1990), Hawkes and Hjerting (1989), Ochoa (1999, 2001); [a] based on Hawkes (1990), Ochoa (2003).

4.1.5 Objectives

The objectives of this article are to investigate three specific components of the annual spatial dimensions of potato diversity in Peru's central Andes. First, the potato cropping and labor calendar(s) with particular emphasis on the role of different footplough-based tillage systems. Second, field scattering practices and their link to the employment of cultivar diversity within potato fields. Third, the relation and interaction between on-farm conservation of infraspecific diversity and the notion of microhabitat adaptation within the Andean cropping environment.

4.2 Materials and methods

This study was conducted in 8 farmer communities following a north-south transect through the department of Huancavelica, Peru (see Chapter 1).

4.2.1 Cropping and labor calendars

A structured surveys was conducted between 2004 and 2005 in order to investigate the potato cropping (n=158 households) and labor calendars (n=137 households). The survey inquired about dates when specific tasks are conducted, time investments, and gender divisions for each of the different footplough-based tillage systems. A team of 3 Quechua speaking fieldworkers was trained in conducting the survey. Descriptive statistics were used to analyze and interpret the data obtained.

4.2.2 Field scattering

A participatory "field scattering" sampling and cartography exercise was conducted in each of the 8 research communities (2004-2005). All potato fields of a total of 122 households were mapped using a Garmin GPSMAP76S global positioning system. An average of 15 households per community participated in the exercise. A total of 601 potato fields were sampled and key parameters, including cultivar composition, end-uses of field content, area (m^2), altitude (m), latitude and longitude registered. Samples of 200 random plants per field were taken during at harvest in order to establish the cultivar composition of each field. The data obtained was interpreted using descriptive statistics, correlation analysis and GIS.

4.2.3. Genotype by environmental management

A genotype by environment (GxE) experiment was conducted following an altitudinal transect in the community of Villa Hermosa. A total of 31 cultivars, consisting of 25 native-floury cultivars, 3 native-bitter cultivars and 3 improved cultivars belonging to *S. goniocalyx* (5), *S. stenotomum* (4), *S. chaucha* (4), *S. juzepczukii* (1), *S. tuberosum* subsp. *tuberosum* (3), *S. tubersosum* subsp. *andigena* (13) and *S. curtilobum* (1), were planted in 4 altitude differentiated environments (F) in on-farm trials covering a total altitude difference of 574 meters (F1= 3,496 m; F2= 3,633 m; F3= 3,729 m; F4= 4,070 m; tables 4.2 and 4.3).

Table 4.2: The four environments along an altitudinal transect

No. field	Farmer field	Sector	Altitude (m)	Coordinates
1	Juan Matamoros Soto	Anco Pico Pampa	3496	18L0515021 / 8587768
2	Antonio Condori Bastides	Qillu Kullu Pampa	3633	18L0513832 / 8588460
3	Juan Ramos Condor	Lirio Cucho	3729	18L0513217 / 8589074
4	Timoteo Ccanto Paytan	Ccochapampa	4070	18L0511573 / 8588514

In each farmer field a completely randomized block design with 3 replicates was installed. Management was homogenous for each of the environments. Soil analyses were conducted and basic climate data measured during the growing season for each of the 4 fields. The effect of environment and genotype by environment interaction (GxE) were analyzed with a two-way AMMI (Additive Main Effects and Multiplicative Interaction; Gauch, 1990, 1992) considering "genotypes" as fixed and "sites" as a random effect. The SAS[6] GLM[7] procedure was used to perform the AMMI analysis using values for potato tuber yield and numbers of tubers obtained per plot across environments.

[6] SAS Institute Inc., 1999. SAS OnlineDoc®, Version 8.2, cary, NC: SAS Institute Inc.

[7] The GLM procedure uses the method of least squares to fit general linear models and includes the statistical method of analysis of variance.

Table 4.3: Cultivars included in the genotype by environmental experiment

No.	Name	CIP Number	Cultivar Category	Species *	Seed Source
1	'Chingos'	703317	Native-floury	Stn	CIP
2	'Leona'	704058	Native-floury	Adg	CIP
3	'Qeqorani'	703287	Native-floury	Stn	CIP
4	'China Runtus'	703825	Native-floury	Gon	CIP
5	'Morada Taruna'	703312	Native-floury	Stn	CIP
6	-	700234	Native-floury	Adg	CIP
7	'Maria Bonita'	-	Improved	Hybrid	Farmer
8	'Mariva'	-	Improved	Hybrid	Farmer
9	'Perricholi'	-	Improved	Hybrid	Farmer
10	'Huamantanga'	-	Native-floury	Cha	Farmer
11	'Camotillo'	-	Native-floury	Gon	Farmer
12	'Saco Largo'	-	Native-floury	Adg	Farmer
13	'Tarmeña'	-	Native-floury	Adg	Farmer
14	'Qullu Papa'	-	Native-floury	Adg	Farmer
15	'Yana Manwa'	-	Native-bitter	Adg	Farmer
16	'Yana Siri'	-	Native-bitter	Juz	Farmer
17	'Qaywa Siri'	-	Native-bitter	Cur	Farmer
18	'Puqya'	-	Native-floury	Stn	Farmer
19	'Ajo Suytu'	-	Native-floury	Cha	Farmer
20	'Wayru Amarillo'	-	Native-floury	Cha	Farmer
21	'Wayru Rojo'	-	Native-floury	Cha	Farmer
22	'Alqay Palta'	-	Native-floury	Adg	Farmer
23	'Trajin Waqachi'	-	Native-floury	Adg	Farmer
24	'Peruanita'	-	Native-floury	Gon	Farmer
25	'Runtus'	-	Native-floury	Gon	Farmer
26	'Ayrampu'	-	Native-floury	Adg	Farmer
27	'Puka Lagarto'	-	Native-floury	Adg	Farmer
28	'Puma Makin'	702395	Native-floury	Adg	CIP
29	'Sullu'	701997	Native-floury	Adg	CIP
30	'Runtus'	708985	Native-floury	Gon	CIP
31	'Ipillu'	-	Native-floury	Adg	Farmer

* Adg= *S. tuberosum* subsp. *andigena*; Cha= *S. chaucha*; Cur= *S. curtilobum*; Gon= *S. goniocalyx*; Juz= *S. juzepczukii*; Stn= *S. stenotomum*

4.3 Results

4.3.1 Labor and cropping calendars

Figure 4.1 shows the basic potato cropping calendars with tasks and time frames as commonly managed by farmers in Huancavelica. The main season (*qatun tarpuy*; literally "big plantings") generally involves numerous potato fields and relatively large areas when compared with the secondary season (*michka*; "small plantings"). Its basic calendar, with planting at the start and harvesting at the end of rainy season, applies to most crop species. The main season (*qatun tarpuy*) involves the cultivation of all potato cultivar categories with high levels of infraspecific diversity while the secondary season (*michka*) generally prioritizes few improved or native-floury cultivars with well-known market demand. The secondary season generally involves a single field per family and one common tillage system (*barbecho*). *Michka* fields are often installed close to the homestead or, in any case, in a well protected area within range of irrigation water. *Michka* plantings are generally small-scale with field sizes ranging between 50 and 350 m²; this is a consequence of limited water availability and high production risks. The secondary season fulfils an important double purpose. First, it provides fresh produce during a time of relative food scarcity more than six months after the *qatun tarpuy* harvest. Second, it commonly provides a means for obtaining high value income as market prices for potato tend to be relatively high between January and March.

Figure 4.1: Potato cropping calendar for the secondary and main season (n=158)

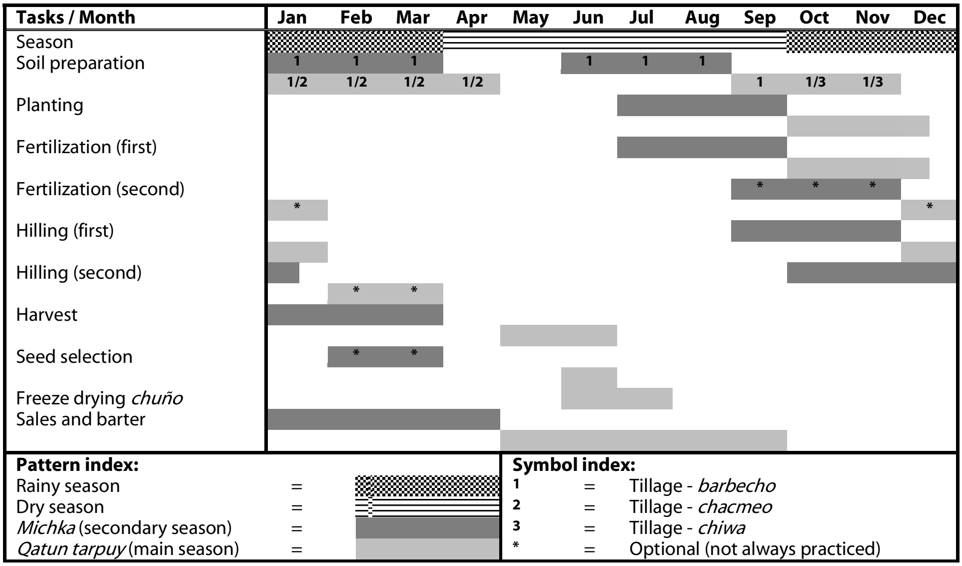


Table 4.4 provides an overview of four different labor calendars, one for the *michka* and three for the *qatun tarpuy* season, each of the later corresponding to a different footplough-based tillage system: *barbecho*, *chacmeo* and *chiwa*. The grey-shaded area indicates the time frame wherein a task is commonly realized. The value in the center of the grey-shaded area refers to the average number of full-time-equivalent (FTE) labor days[1] needed to fulfill the specific task based on survey data.

Barbecho is a well-known system of tillage and consists of turning, breaking and loosening the soil before the actual act of planting tubers, followed by two separate moments of hilling at intermediate stages of vegetative plant development. *Barbecho* tillage is commonly practiced for improved cultivars and commercial native-floury cultivars. The system is labor intensive with a total average of 117 and 121 FTE labor days required for cropping one hectare during the *michka* and *qatun tarpuy* season respectively. Labor peaks for tillage during the main season are concentrated between January - April (24 FTE days / ha; turning), September - November (18 FTE days / ha; breaking), December - January (14 FTE days / ha; first hilling), and February - March (10 FTE days / ha; second hilling).

Table 4.4: Potato labor calendar for the main and secondary seasons (n=137)

	Tasks	Average Number of Adult FTE Working Days per Hectare												Labor division (%)	
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	♀	♂
BARBECHO *Michka*	SP: turning		24											0	100
	SP: breaking							18						14.7	85.3
	Planting								8					47.8	52.2
	Fertiliz. I								¥					47.8	52.2
	Fertiliz. II										8			27.6	72.4
	Hilling-up I										14			1.2	98.8
	Hilling-up II	1										9		2.9	97.1
	Crop prot.	1										3		1.7	98.3
	Cutting fol.	4											2	78.6	21.4
	Harvesting		20											43.2	56.8
	Selection		5											67.3	32.7
	TOTAL	**20.3**	**18.3**	**16.3**			**6.0**	**8.7**	**8.7**	**10.0**	**10.3**	**11.8**	**6.5**	**117 days**	
BARBECHO *Qatun Tarpuy*	SP: turning		24 *											0	100
	SP: breaking										18 *			13.1	86.9
	Planting											8		48.8	51.2
	Fertiliz. I											¥		48.8	51.2
	Fertiliz. II	4											4	24.3	75.7
	Hilling-up I	7											7	2.3	97.7
	Hilling-up II		10											2.9	97.1
	Crop prot.		2										1	5.2	94.8
	Cutting fol.				9									76.9	23.1
	Harvesting					20 **								38.8	61.2
	Selection						7							56.4	43.6
	TOTAL	**17.7**	**11.7**	**14.7**	**9.0**	**16.5**	**13.5**			**6.0**	**10.0**	**10.0**	**12.0**	**121 days**	
CHACMEO *Qatun Tarpuy*	SP: turning		18 * [a]											29.2	70.8
	Planting											8		47.1	52.9
	Fertiliz. I											¥		47.1	52.9
	Fertiliz. II	4											4	32.6	67.4
	Hilling-up I	8											8	1.9	98.1
	Crop prot.		2										1	6.7	93.3
	Cutting fol.				9									85.3	14.7
	Harvesting						18 **							40.3	59.7
	Selection					7								62.1	37.9
	TOTAL	**17,2**	**5,2**	**8,2**	**7,5**	**15,5**	**12,5**				**4,0**	**4,0**	**13,0**	**87 days**	
CHIWA *Qatun Tarpuy*	Opening hole											§		47.8	52.2
	Planting											8		47.8	52.2
	Fertiliz. I											¥		47.8	52.2
	Fertiliz. II	4											4	34.8	65.2
	Hilling-up I	10											10	0	100
	Crop prot.		2										1	10.9	89.1
	Cutting fol.				9									92.1	7.9
	Harvesting						23 **							27.7	72.3
	Selection						7							70.3	29.7
	TOTAL	**14.7**	**0.7**	**3.7**	**3.0**	**18.0**	**15.0**				**4.0**	**4.0**	**15.0**	**78 days**	

SP= soil preparation; ¥= first fertilization (handful of dung) is done simultaneously with planting; §= opening a hole with the footplow to deposit seed is done simultaneously with planting; *= main task and moment for practicing *ayni* (labor sharing between families; symmetrical exchange). **= main task and moment for practicing *minka* (help at harvest for payment in potatoes; asymmetrical exchange); [a]= main moment for the traditional *yupanakuy* (competition between farmer groups and communities in *chacmeo* tillage).

Chacmeo[9] is a type of minimal-tillage and consist of turning two clods of soil on top of the pasture. This is done in a continuous and rhythmic fashion in order to form a row, generally with two man turning the clods in opposite directions with their *chakitaklla* and one person (man or woman) accommodating the clods on top of the pasture. Tubers are planted in between the clods and the potato crop actually grows above the pasture level. *Chacmeo* tillage is mostly practiced for native cultivars, but sporadically also for improved cultivars. The system is moderately labor extensive with a total average of 87 FTE labor days required for a hectare. Labor peaks for tillage are concentrated between January - April (18 FTE days / ha; turning) and December - January (16 FTE days / ha; first and only hilling).

Chiwa[10] is another type of minimal-tillage which starts with a man making an opening in the pasture with his *chakitaklla* while another person, often a woman, deposits a seed potato in the opening and covers it up by stepping on it. *Chiwa* is often practiced as a kind of last-minute planting and provides an easy way of planting potatoes during a period when labor availability is scarce. The system is commonly practiced for both native-bitter and native-floury cultivars. *Chiwa* is least labor demanding when compared with *barbecho* and *chacmeo*; an average of 78 FTE labor days are needed for cropping one hectare. Labor peaks for tillage are concentrated between October - November (8 FTE days / ha: opening hole and planting) and December - January (20 FTE days / ha; first and only hilling).

Table 4.5 shows the relative importance of the different tillage systems for the cultivation of 8 different potato cultivars. Improved cultivars are predominantly grown using the *barbecho* tillage system while native-bitter cultivars are generally cultivated using the *chiwa* tillage system. Commercial native-floury cultivars such as *Peruanita* and *Runtus* are more frequently subjected to *barbecho* tillage compared to non-commercial native-floury cultivars such as *Puqya* and *Pumapa Makin*. The latter are more frequently grown under the *chiwa* tillage regime. *Chacmeo* tillage is infrequently applied to any of the cultivars.

Table 4.5: Percentages (%) of fields managed with specific tillage systems (8 different cultivars)

	Native-floury cultivars				**Native-bitter cultivars**		**Improved cultivars**	
	Peruanita **(n[1]=255)**	***Runtus*** **(n=223)**	***Puqya*** **(n=115)**	***Pumapa Makin*** **(n=22)**	***Siri*** **(n=53)**	***Manwa*** **(n=92)**	***Yungay*** **(n=201)**	***Canchan*** **(n=116)**
Barbecho	64.3	53.4	30.4	40.9	11.3	25.0	72.1	70.7
Chacmeo	9.0	6.3	11.3	13.6	9.4	9.8	7.0	4.3
Chiwa	26.7	40.4	58.3	45.5	79.2	65.2	20.9	25.0

[1] = potato fields

Gender based labor divisions for specific tasks exist. Heavy work such as turning and breaking of the soil and hilling are predominantly done by man. Typical female tasks are cutting of the potato foliage for animal feed and to hasten ripening, and to a lesser extent seed selection. The actual tasks of planting and harvesting are often shared between man and women with the exception of the *chiwa* harvest which is predominantly done by man.

4.3.2 Field scattering

Field scattering strongly shapes Huancavelica´s agricultural landscape. Overall, households

[9] Depending on the specific region within Huancavelica *chacmeo* is also known as *chacma* or *suca*.
[10] Depending on the specific region within Huancavelica *chiwa* is also known as *qaqi*, *imicha*, *tipka* or *yakuycha*.

manage a yearly average of 4.9 (± 2.9) scattered potato fields per family during the main season. A total of 93.4% of the households cultivated native-floury cultivars, 66.4% improved cultivars and only 26.2% native-bitter cultivars. Generally more fields and area are planted with native-floury cultivars compared to native-bitter or improved cultivars, except in the community of Allato where families tend to dedicate more fields and area to improved potato cultivars. Considerable differences concerning the number of potato fields per household, the total potato cropping area per household, the potato cropping area per field, and the number of potato cultivars per field exist between and within communities (tables 4.6, 4.7, 4.8 and 4.9). While farmers in the more market-connected community of Huayta Corral cultivate an average of 9.1 (± 2.9) scattered potato fields and total average area of 11,301 m² (1.1 ± 0.5 ha.) per household (maximum registered), farmers in the community of Pucara only manage an average of 3.2 (± 2.1) scattered potato fields and total average area of 2,753 m² (0.3 ± 0.2 ha.) per household (minimum registered). None of the households in Allato and Pongos Grande grew native-bitter cultivars. Farmer family's dedication to the cultivation of improved potato cultivars also varied strongly among communities. A minimum of 18.8% and maximum of 100% of families grew improved cultivars in the communities of Villa Hermosa and Huayta Corral respectively.

The cultivation of mixed cultivar stands, called *chaqru* in the Quechua language, is common with an average of 90.4% and 84.8% of all sampled fields with native-floury and native-bitter cultivars containing complete cultivar mixtures. Mixing was less common for fields containing improved cultivars (29.8%). Regional within field diversity averaged 16.7 (± 18.4), 4.4 (± 2.4) and 2.2 (± 2.2) cultivars per field of native-floury, native-bitter and improved cultivars respectively (table 4.9). Overall within field diversity, independently of the cultivar category, fluctuated between a minimum of 3.2 (± 3.8) and a maximum of 32.0 (± 24.7) cultivars per field for the communities of Huayta Corral and Villa Hermosa respectively. Figure 4.2 shows the diversity profiles for all surveyed families from these 2 communities. Each bar represents an individual family (F) with the total number of cultivars grown (different colors) and their relative abundance (length of each color on the bar) in relation to the total sample size. It is clear that family cultivar stocks are more diverse in the community of Villa Hermosa when compared with Huayta Corral. Even though farmer families in the community of Huayta Corral practice intensive field scattering and manage relatively large potato cropping areas, family diversity profiles are characterized by relatively few cultivars dominating the total sample.

Table 4.6: Number of potato fields per household: total, native-floury, native-bitter, improved (*)

Community	Number of families sampled (n)	Number of Potato Fields per Household									
		Total				Native-floury		Native-bitter		Improved	
		Av.	SD (±)	Min.	Max.	Av.	SD (±)	Av.	SD (±)	Av.	SD (±)
Huayta Corral	15	9.1	2.9	4	16	5.3	2.4	1.8	0.5	3.3	1.7
Tupac Amaru	16	5.3	2.1	1	9	3.5	1.4	1.8	1.1	1.4	0.6
Villa Hermosa	16	5.1	3.3	2	13	3.9	2.6	1.4	1.1	2.3	1.5
Pucara	15	3.2	2.1	1	8	3.1	2.1	1.0	0	1.8	1.2
Dos de Mayo	15	5.3	3.2	1	13	3.7	1.9	1.6	1.3	1.6	0.7
Libertadores	15	3.9	1.6	2	8	2.9	1.6	1.1	0.4	1.1	0.4
Pongos Grande	15	4.1	1.5	2	7	2.6	1.6	0	0	2.6	0.9
Allato	15	3.5	1.8	1	6	1.7	1.2	0	0	2.5	1.8
TOTAL	122	4.9	2.9	1	16	3.4	2.1	1.4	0.9	2.1	1.4

*= Table based on main season (*qatun tarpuy*) plantings

Table 4.7: Total potato cropping area (m²) per household: total, native-floury, native-bitter, improved (*)

Community	Number of families sampled (n)	Potato Cropping Area (m²)									
		Total Potato				Native-floury		Native-bitter		Improved	
		Av.	SD (±)	Min.	Max.	Av.	SD (±)	Av.	SD (±)	Av.	SD (±)
Huayta Corral	15	11,301	4,692	5,430	20,363	7,804	4,895	2,143	1,417	2,925	1,363
Tupac Amaru	16	7,138	4,236	464	18,770	5,087	3,116	1,613	1,486	1,769	979
Villa Hermosa	16	3,340	2,136	525	9,276	2,686	2,012	749	625	1,493	1213
Pucara	15	2,753	1,840	256	6,235	2,635	1,735	678	238	1,614	1323
Dos de Mayo	15	5,251	4,208	642	12,872	3,482	2,949	1,833	1599	1,738	1933
Libertadores	15	3,974	2,028	898	7,892	2,905	1,608	1,390	651	900	558
Pongos Grande	15	6,408	3,134	2,333	14,137	4,781	3,104	0	0	2,219	1627
Allato	15	4,753	4,730	944	19,792	2,502	1,757	0	0	3,175	3909
TOTAL	122	5,609	4,303	256	20,363	4,082	3,306	1,361	1,118	2,165	2061

*= Table based on main season (*qatun tarpuy*) plantings

Table 4.8: Potato cropping area (m²) per field: total, native-floury, native-bitter, improved

Community	Number of families sampled (n)	Potato Cropping Area (m²) per Field									
		Total				Native-floury		Native-bitter		Improved	
		Av.	SD (±)	Min.	Max.	Av.	SD (±)	Av.	SD (±)	Av.	SD (±)
Huayta Corral	15	1,246	989	78	6,923	1,463	1,130	1,225	593	896	633
Tupac Amaru	16	1,344	1,165	184	6,731	1,453	1,270	896	1,223	1,238	744
Villa Hermosa	16	660	482	87	2,959	682	515	544	290	640	435
Pucara	15	860	592	76	2,732	850	571	678	238	923	702
Dos de Mayo	15	997	969	103	5,182	950	870	1,146	784	1,086	1359
Libertadores	15	1,010	643	141	3,391	1,013	711	1,217	348	788	406
Pongos Grande	15	1,576	1,143	143	4,731	1,839	1,201	0	0	1,110	875
Allato	15	1,371	1,217	191	6,012	1,501	1,226	0	0	1,290	1,223
TOTAL	122	1,139	980	76	6,923	1,202	1,035	947	725	1044	897

Table 4.9: Number of potato cultivars per field: total, native-floury, native-bitter, improved (n=122)

Community	Number of Potato Cultivars per Field															
	Total				Native-floury				Native-bitter				Improved			
	Av.	SD (±)	Min.	Max.	Av.	SD (±)	Min.	Max.	Av.	SD (±)	Min.	Max.	Av.	SD (±)	Min.	Max.
Huayta Corral	3.2	3.8	1	26	4.1	4.5	1	26	2.4	2.1	1	7	1.7	1.1	1	4
Tupac Amaru	9.0	9.7	1	46	11.7	11.5	1	46	3.2	1.0	2	5	3.2	1.5	1	5
Villa Hermosa	32.0	24.7	2	95	38.6	23.3	3	95	6.0	2.0	4	11	3.5	1.7	2	5
Pucara	16.6	16.9	1	59	23.4	17.4	2	59	4.7	0.6	4	5	2.2	1.6	1	5
Dos de Mayo	9.8	10.0	1	61	12.0	10.7	1	61	3.8	1.9	1	7	2.2	1.6	1	5
Libertadores	8.3	6.7	1	29	9.5	7.2	1	29	6.0	3.1	1	9	1.8	0.8	1	3
Pongos Grande	13.7	11.8	1	42	18.0	12.3	1	42	0	0	0	0	2.5	1.3	1	5
Allato	14.0	20.3	1	107	28.3	26.2	1	107	0	0	0	0	2.1	1.0	1	4
TOTAL	12.3	16.2	1	107	16.7	18.4	1	107	4.4	2.4	1	11	2.2	2.2	1	5

High levels of cultivar diversity within fields, particularly for the category of native-floury cultivars, are strongly concentrated at particular altitudes. Figure 4.3 shows that the highest levels of infraspecific diversity within fields containing native-floury cultivars are found between 3,850 and 4,150 m with an average of 15.0 to 19.7 cultivars per field. Cultivar diversity within fields containing native-floury cultivars drop sharply at lower (<3,850 m) and higher (>4,150 m) altitudes. The altitudinal concentration of infraspecific diversity within fields when overlapped with additional information, including slope and land use data, was used to create maps specifying cultivar diversity hotspots (fig. 4.4). The highest levels of infraspecific diversity for native-bitter cultivars are concentrated between 4,050 and 4,150 m of altitude with an average of 4.1 cultivars per field. However, bitter cultivars only start to appear above 3,750 m and differences concerning infraspecific field diversity by altitudinal range are modest. The levels of cultivar diversity within fields containing improved cultivars only fluctuated modestly with a minimum of 1.0 (3,350-3450m; 4,250-4,350m) and maximum of 2.9 cultivars per field (3,950-4,050 m).

Figure 4.2: Average within field distribution of cultivar diversity - Huayta Corral / Villa Hermosa

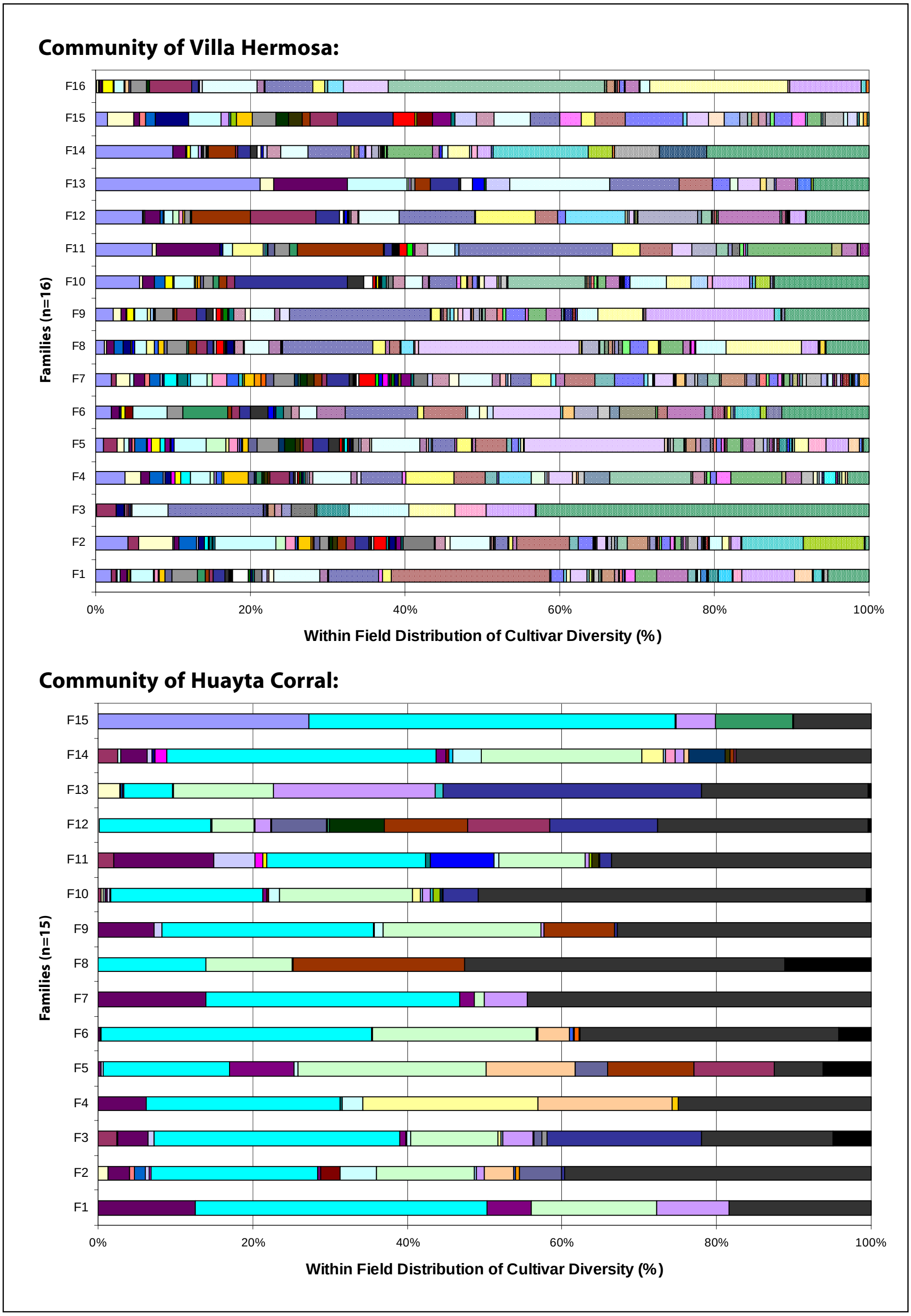
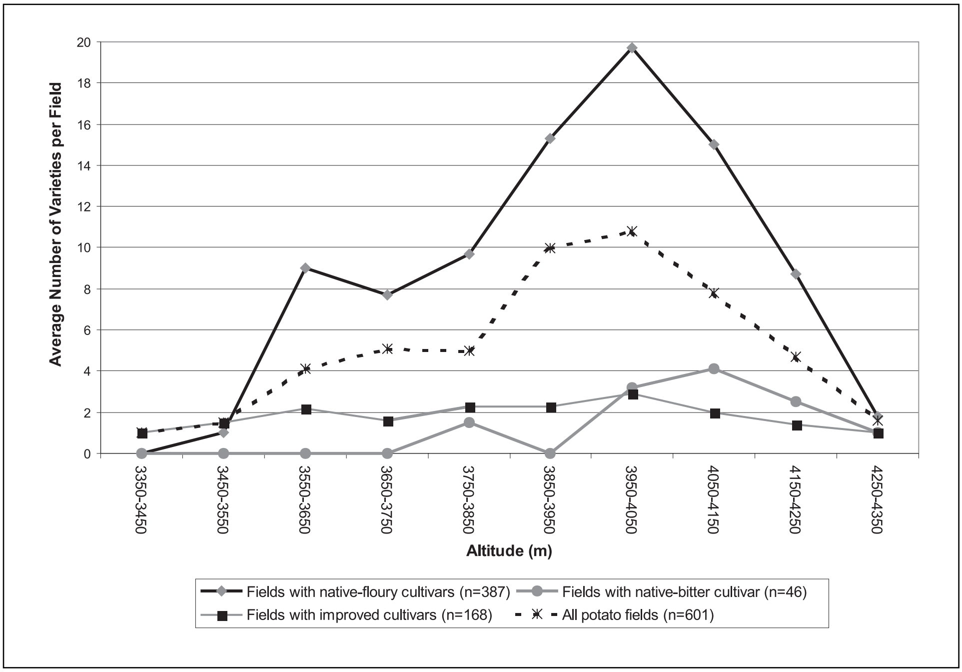


Figure 4.3: Average number of cultivars per field by altitudinal ranges[1] (100 m)



[1]= based on data from all of the eight research communities

Figure 4.4: Map of cultivar diversity hotspots for the community of Tupac Amaru (native floury cultivars)

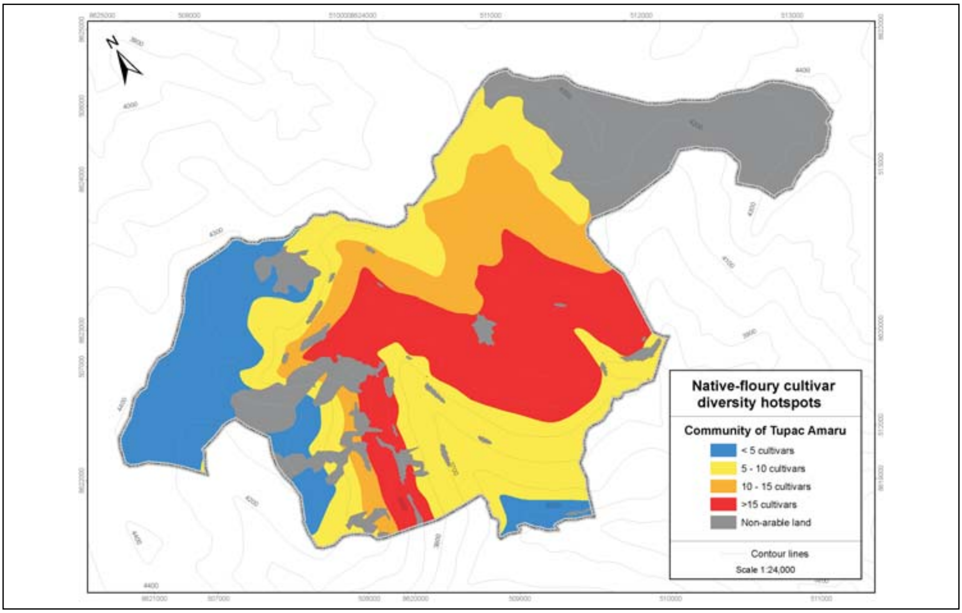
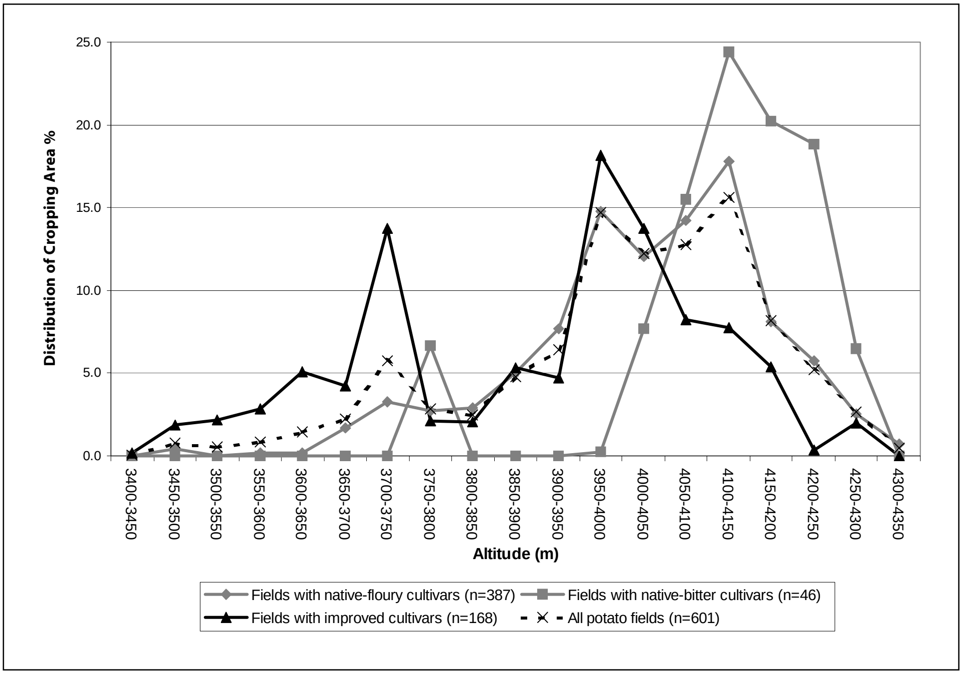


Figure 4.5 shows the altitudinal distribution of the potato cropping area by cultivar category for all the communities. Improved cultivars occupy an extensive altitude range covering areas between 3,450 up to 4,300 m. The altitudinal median for the areal distribution of improved cultivars lies between 3,950 and 4,000 m. Native-bitter cultivars occupy a restricted altitudinal range with 93.3% of the total cropping area located between 3,950 and 4,300 m. Native-bitter cultivars specifically occupy cropping areas located at the upper limits of the agricultural frontier. The altitudinal median for areal distribution of native-bitter cultivars lies between 4,100 and 4,150 m. Native-floury cultivars are characterized by a distribution pattern that lies somewhere in the middle. Native-floury cultivars occupy a fairly extensive altitudinal range and predominantly cover areas between 3,700 and 4,250 m with extreme low-altitude records at 3,400-3,450 m and high-altitude records at 4,300-4,350 m. The altitudinal median for areal distribution lies between 4,000 and 4,050 m, only 50 m higher than improved cultivars and 100 m lower than native-bitter cultivars. This clearly indicated that considerable overlap exists for the altitudinal distribution of the cultivar categories.

Figure 4.5 Altitudinal distribution (%) of cropping area (N=601) by cultivar category (50 m intervals)



This altitudinal distribution patterns for fields containing the three cultivar categories remains apparent when zooming into specific cultivars belonging to each of the categories. Figure 4.6 and table 4.10 show the distribution patterns of 4 native-floury, 2 native-bitter and 2 improved cultivars (averaged over all communities). The improved cultivars *Yungay* and *Canchan* cover an extended altitudinal range of 900 meters while the native-bitter cultivars *Siri* and *Manwa* occupy a more restricted range covering an altitude difference of 500 to 600 meters. The native-floury cultivars *Peruanita*, *Runtus* and *Puqya* cover intermediate ranges of 700 to 800 meters. The rare cultivar *Pumapa Makin* is an exception and only covers 500 meters of altitude difference. All cultivars except *Puqya*, *Manwa* and *Siri* have their median between 3,950 and 4,050 meters above sea level. This finding reaffirms that improved and native-floury cultivars are commonly found within similar altitudinal ranges. The native-bitter cultivars *Siri* and *Manwa* have their median at a higher altitudinal range when compared with most improved cultivars and native-floury cultivars. So does the robust native-floury cultivar *Puqya*; farmers often cultivate it in similar conditions as native-bitter cultivars because of its well-known tolerance to adverse conditions such as frosts and hails.

The deployment of varying levels of cultivar diversity within scattered fields containing native-floury cultivars is also a response to different end-uses of field content (table 4.11). An overall modest positive correlation exists between high infraspecific diversity and the exclusive use of produce for home consumption: 42.4% of all fields containing native-floury cultivars were exclusively used for home consumption and overall these fields contained higher levels of infraspecific diversity when compared with the total sample size of fields containing native-floury cultivars (n=387). No significant positive or negative correlation exists between field diversity versus the exclusive use of produce for sales; this because fields containing native-floury cultivars were rarely exclusively destined for sales. An overall modest negative correlation exists between high infraspecific diversity and double purpose use of field production. So fields installed for partial sales contained lower levels of cultivar diversity when compared with fields planted exclusively for home consumption. Overall positive, albeit modest, significant correlations exist between high levels of infraspecific diversity and the use of field produce for barter, seed and *chuño* (freeze-drying).

Figure 4.6: Altitudinal distribution (%) of potato fields (N=601) for specific cultivars (100 m intervals)

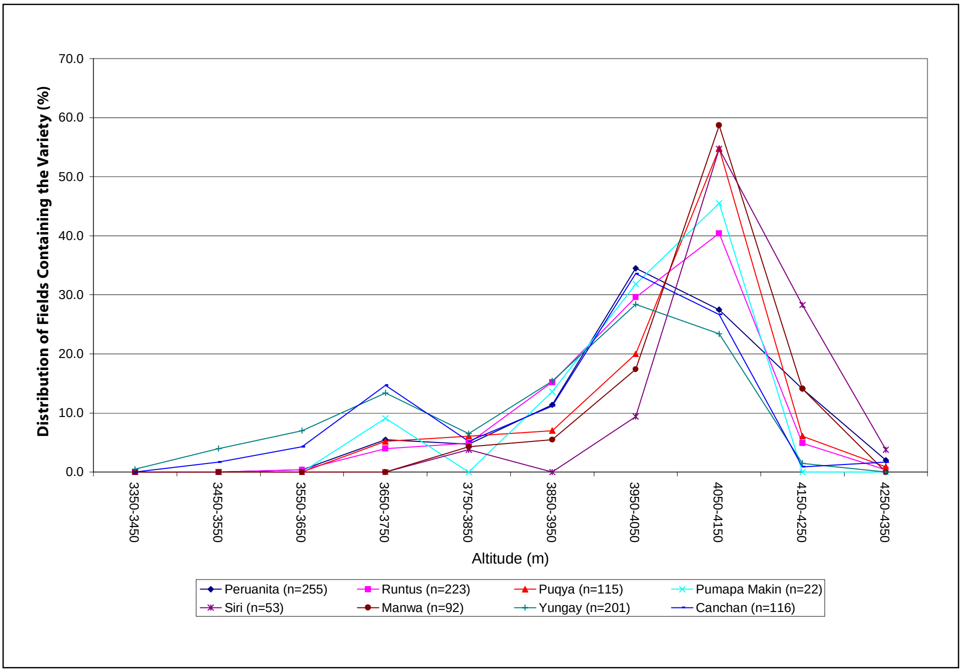


Table 4.10: Altitudinal distribution (%) of potato cropping area (N=601) for specific cultivars (100 m intervals)

Cultivar name	Cultivar category	Attitudinal Range (m)		Median (m)
		Min. / Max.	Difference	
1. 'Peruanita'	Native-floury	3,550 - 4,350	800	3,950 - 4,050
2. 'Runtus'	Native-floury	3,550 - 4,350	800	3,950 - 4,050
3. 'Puqya'[1]	Native-floury	3,650 - 4,350	700	4,050 - 4,150
4. 'Pumapa Makin'[2]	Native-floury	3,650 - 4,150	500	3,950 - 4,050
5. 'Siri'	Native-bitter	3,750 - 4,350	600	4,050 - 4,150
6. 'Manwa'	Native-bitter	3,750 - 4,250	500	4,050 - 4,150
7. 'Yungay'	Improved	3,350 - 4,250	900	3,950 - 4,050
8. 'Canchan'	Improved	3,450 - 4,350	900	3,950 - 4,050

[1] = robust native-floury cultivar; [2] = scarce native-floury cultivar

Table 4.11: Intended purpose of native-floury potato field produce and correlation coefficients for infraspecific field diversity (n=387)

Community	Exclusively home consumption		Exclusively sales		Double purpose: consum. and sales		Barter		Seed		*Chuño*	
	Perc. fields (%)	Cor. coeff. diversity (r)	Perc. fields (%)	Cor. coeff. diversity (r)	Perc. fields (%)	Cor. coeff. diversity (r)	Perc. fields (%)	Cor. coeff. diversity (r)	Perc. fields (%)	Cor. coeff. diversity (r)	Perc. fields (%)	Cor. coeff. diversity (r)
Huayta Corral	17.5	0.02	5.0	-0.14	73.8	-0.07	18.8	0.09	50.0	0.17	46.3	0.17
Tupac Amaru	28.6	0.53 ***	8.9	-0.03	60.7	-0.41 ***	33.9	-0.07	71.4	-0.25	44.6	-0.30 *
Villa Hermosa	66.7	-0.09	4.8	0.01	23.8	0.17	36.5	0.28 *	92.1	0.07	88.9	0.14
Pucara	22.6	-0.43 *	0	-	77.4	0.43 *	45.2	-0.07	90.3	0.16	77.4	0.20
Dos de Mayo	65.5	0.37 **	3.6	-0.22	25.5	-0.18	10.9	0.20	90.9	0.28 *	74.6	0.30 *
Libertadores	90.7	0.02	0	-	9.3	-0.02	18.6	0.01	88.4	-0.17	90.7	-0.17
Pongos Grande	12.8	-0.06	0	-	87.2	0.06	46.2	0.56 ***	61.5	0.40 *	43.6	0.38 *
Allato	25.0	-0.12	0	-	75.0	0.12	25.0	0.12	70.0	0.30	50.0	0.19
TOTAL	42.4	0.18 ***	3.6	-0.07	51.4	-0.13 ***	27.9	0.20 ***	75.5	0.24 ***	64.3	0.21 ***

*** p>0.001; ** p> 0.01; * p>0.05

4.3.3 Genotype by environmental management

The agronomic management of the GxE experiment was homogeneous, so principal sources of environmental variation included soil characteristics and climate (tables 4.12 and 4.13). The texture of soils from all fields was very similar and contained high percentages of sand. All the soils were acid and rich in organic matter with some notable differences between fields. Soils from all fields contained high values of total nitrogen (N). Soils from fields 1 and 2 contained medium-high levels and soils from fields 3 and 4 low levels of available phosphorus (P). Soils from fields 2 and 3 contained high levels of available potassium (K); soils from fields 1 and 4 medium and low levels. Considerable differences were observed between sites concerning the average temperature. As expected, differences between the low and high altitudinal extremes were particularly large with an average temperature difference of 4.7 ºC. Average temperature differences between field 2 and 3 were minimal. Differences between all fields concerning the average relative humidity were modest.

Table 4.12: Basic soil characteristics for the four environments

	Field 1 Anco Pico Pampa 3,496 masl	Field 2 Qillu Kullu Pampa 3,633 masl	Field 3 Lirio Cucho 3,729 masl	Field 4 Ccochapampa 4,070 masl
Texture:				
Sand (%)	65.9	67.9	60.7	62.0
Clay (%)	12.6	14.8	20.2	11.3
Lime (%)	21.4	17.3	19.1	26.7
Chem. properties:				
pH	4.5	5.7	5.9	4.4
Organic matter (%)	4.7	11.6	10.7	11.1
Total N (%)	0.160	0.310	0.290	0.300
Available P (ppm)	7.00	9.00	5.00	5.00
Available K (ppm)	186.00	226.00	290.00	90.00
Ca (Meq/100g)	6.30	11.20	18.50	13.00
Mg (Meq/100g)	0.86	3.06	2.05	1.15
C/N	17.04	21.65	21.32	21.37

masl= meters above sea level

Table 4.13: Average, minimum and maximum temperature and humidity by environment (altitudinal transect, community of Villa Hermosa, Huancavelica)

	Field 1 Anco Pico Pampa 3,496 masl			Field 2 Qillu Kullu Pampa 3,633 masl			Field 3 Lirio Cucho 3,729 masl			Field 4 Ccochapampa 4,070 masl		
	Av.	Min.	Max.	Av.	Min.	Max.	Av.	Min.	Max.	Av.	Min.	Max.
T (ºC):												
Average	12.7	10.0	17.0	11.2	8.8	15.3	11.1	8.7	15.2	8.0	4.4	12.0
Minimum	6.7	0.5	10.0	5.9	0.3	11.9	6.2	1.6	10.2	3.6	-2.9	8.2
Maximum	23.3	14.9	32.1	18.7	12.3	35.1	18.3	11.4	26.5	13.8	8.5	26.3
R.H. (%):												
Average	67.4	17.8	85.3	70.4	18.4	90.5	67.9	18.9	88.3	69.5	15.9	90.8
Minimum	34.8	5.8	70.0	43.6	6.2	75.5	45.0	6.6	77.9	48.6	8.15	82.2
Maximum	88.0	24.5	96.3	90.5	27.0	99.5	85.5	34.5	95.8	86.0	30.2	96.8

Additive main effect and multiplicative interaction (AMMI) analysis of variance for total tuber yield (g/plant) of 31 genotypes in 4 environments at different altitudes showed that 41.70% of the total sum of squares was attributable to genotypic effects, 17.04% to environmental effects, and only 14.44% to GxE interaction effects. A similar tendency with primary attribution to the genotypic effect can also be observed for marketable tuber yield[11] (g/plant), total number of tubers per plant, and number of marketable tubers per plant (table 4.14). The small sum of squares for environments indicates that the environments did not cause most of the variation for the studied variables. The magnitude of the GxE interaction sum of squares was 6-times lower than the genotypic interaction alone, indicating that there were no big differences in genotypic responses across environments.

[11] Farmers in Huancavelica commonly select and separate the total potato harvest into four categories: a.) big size tubers for commercialization (*qatun* or *primera*), b.) medium-big size tubers for home consumption (*consumo* or *segundo*), c.) medium-small tubers for seed (*semilla* or *tercera*), d.) small tubers for freeze-drying (*chuño* or *cuarta*). Marketable refers to those tubers belonging to the first two categories (a + b).

The mean squares of the interaction principal component axis IPCA-1 and IPCA-2 for total tuber yield, marketable tuber yield, and the total number of tubers per plant were significant at 0.01 and cumulatively contributed 85.53%, 85.27%, and 87.09% of the total GxE interactions. Post predictive evaluation for these three variables using the F-test at 0.01 confirms that the two interaction principal component axes were significant for the model with 62 degrees of freedom. Tables 4.15 and 4.16 show mean values for the variables and coordinates of the first and second components (IPCA-1 and IPCA-2) by genotypes and environments. The significance of between site variations in these tables is based on analysis of variance (ANOVA) for genotypes and environments.

Biplots were generated using genotypic and environmental scores of the first two AMMI components (Vargas and Crossa, 2000). Genotypes and environments with similar IPCA coordinates interact positively and are grouped in the same quadrant. Figure 4.7 shows the biplot for total tuber yield. Environments F1, F2+F3 and F4 fall into a different quadrants with some specific genotypes performing best in a particular environment, e.g. the cultivar *Ipillu* (31) in the highest environment (F4) and the cultivar *Qullu Papa* (14) in the lowest environment (F1). The most stable genotypes with low near zero values for IPCA-1 and IPCA-2 and total yields (g/plant) above the general mean are 12, 22, 23, 26 and 29. Stable genotypes with total yield levels below the general mean are 1, 20, 25 and 28. The improved cultivar *Perricholi* (9) showed the highest total average yield, but was non-stable through sites. By contrast, the improved cultivar *Maria Bonita* (7) yielded poorly at all sites. The high-altitude environment F4 (4,070 m) showed the highest interaction effect for total yield in comparison with the other environments. The IPCA-1 and IPCA-2 scores for environment F2 and F3 showed similar interaction effects. The general tendency for the non-stable cultivars was to show lower levels of total yield by increased altitude. A gradual total yield decline by increased altitude was evident for 11 out of 19 cultivars with significant yield differences between sites based on ANOVA, including all improved cultivars (fig. 4.8). Results for marketable tuber yield were similar with 16 genotypes showing significant differences between sites based on ANOVA. Interaction for the total number of tubers per plant and number of marketable tubers per plant was modest with only 6 and 7 genotypes showing significant differences respectively.

Table 4.14: Additive main effect and multiplicative interaction analysis (AMMI) for total and marketable tuber yield (g/plant), and total and marketable number of tubers per plant

Source	d.f.	Total tuber yield (g/plant)				Marketable tuber yield (g/plant)				Total no. of tubers /plant				No. of marketable tubers/ plant			
		Sum of square	Mean square	Sig.	Explains (%)	Sum of square	Mean square	Sig. (%)	Explains	Sum of square	Mean square	Sig.	Explains (%)	Sum of square	Mean square	Sig.	Explains (%)
Corrected tot.	371	11.30				17.25				272.25				106.06			
Rep. by Env.	8	0.36	0.04	**	3.15	0.53	1.84	**	3.07	5.73	10.81	**	2.11	13.47	1.68	**	12.70
Environment	3	1.92	0.64	**	17.03	2.04	0.68	**	11.85	2.52	1.23	**	0.93	2.02	0.67	**	1.91
Genotype	30	4.71	0.16	**	41.70	8.90	0.30	**	51.61	193.02	21.68	**	70.90	35.78	1.19	**	33.74
Gen. by Env.	90	1.63	0.02	**	14.44	2.22	0.02	**	12.89	30.87	13.88	**	11.34	22.47	0.25	**	21.19
InteractionPCA1	32	0.80	0.03	**	49.24	1.17	0.04	**	52.52	16.23	0.51	**	52.57	10.02	0.31	**	44.61
InteractionPCA2	30	0.59	0.02	*	36.29	0.73	0.02	*	32.75	10.66	0.36	**	34.52	6.82	0.23		30.36
InteractionPCA3	28	0.24	0.01		14.42	0.33	0.01		14.73	3.99	0.14		12.93	5.63	0.20		25.07
InteractionPCA4	26	0.00	0.00		0.00	0.00	0.00		0.00	0.00	0.00		0.00	0.00	0.00		0.00
Error	240	2.67	0.01			3.55	0.01			40.11	11.30			32.31	0.13		
Mean			1008.21				836.04				18.72				9.84		
Coeff. variation			3.55				4.23				9.64				11.87		
R-Square			0.76				0.80				0.85				0.70		

** p>0.01; * p>0.05

Table 4.15: Means of the cumulative variables, environments (E) and genotypes (G), and environment and genotype coordinates of the first and second IPCA axis

Genotype	C.C.	Species	Total tuber yield (g/plant)								Marketable tuber yield (g/plant)							
			F1	F2	F3	F4	XG	Sig.[a]	IPCA_1	IPCA_2	F1	F2	F3	F4	XG	Sig.[a]	IPCA_1	IPCA_2
1. 'Chingos'	NF	Stn	1303	873	770	738	921	*	0.04	0.07	1162	725	643	657	797		-0.03	0.05
2. 'Leona'	NF	Adg	686	511	626	623	612		0.14	-0.15	214	317	257	226	254		-0.63	-0.20
3. 'Qeqorani'	NF	Stn	1408	987	793	754	985	*	0.01	0.10	1200	840	581	562	796	**	0.00	0.14
4. 'C. Runtu'	NF	Gon	1307	778	592	722	850	**	0.13	0.16	1014	626	478	620	685	**	0.40	0.06
5. 'M. Taruna'	NF	Stn	1035	1368	860	582	961	**	-0.24	-0.03	912	1201	709	513	834	**	-0.20	0.06
6. CIP-700234	NF	Adg	1203	1477	971	939	1147		-0.05	-0.11	1216	1339	910	855	1080		0.00	-0.04
7. 'M. Bonita'	IMP	Hybrid	511	631	509	260	478	**	-0.26	-0.01	395	533	423	189	385	**	-0.11	0.11
8. 'Mariva'	IMP	Hybrid	1760	1599	1294	615	1317	**	-0.32	0.16	1575	1329	1128	546	1144	**	-0.08	0.27
9. 'Perricholi'	IMP	Hybrid	2491	1671	1246	1127	1634	**	-0.01	0.18	1936	1682	1217	1008	1461	*	0.34	0.08
10. 'Huaman.'	NF	Cha	856	936	694	698	796		-0.01	-0.11	600	527	518	549	549		-0.33	-0.14
11. 'Camot.'	NF	Gon	1030	776	917	643	842		-0.03	0.00	781	643	738	525	672		-0.07	-0.02
12. 'S. Largo'	NF	Adg	1506	1253	977	855	1148	*	-0.04	0.06	1350	1034	693	722	950	*	0.05	0.10
13. 'Tarmeña'	NF	Adg	1056	985	844	904	947		0.07	-0.11	590	753	612	664	655		0.00	-0.24
14. 'Q. Papa'	NF	Adg	1365	722	657	751	874	**	0.16	0.16	1176	507	536	667	721	**	0.49	0.08
15. 'Y. Man.'	NB	Adg	1555	1130	1167	1261	1278		0.14	-0.05	1339	1004	1018	1100	1115		0.20	-0.10
16. 'Y. Siri'	NB	Juz	1012	1574	1050	914	1137	*	-0.14	-0.24	849	1392	906	976	1031		-0.28	-0.27
17. 'Q. Siri'	NB	Cur	978	1093	989	570	908	**	-0.19	-0.04	779	1061	846	407	773	**	-0.17	0.10
18. 'Puqya'	NF	Stn	983	1038	768	607	849	*	-0.12	-0.05	757	826	571	474	657		-0.15	0.01
19. 'A. Suytu'	NF	Cha	880	992	707	937	879		0.12	-0.19	844	807	491	771	728	*	0.16	-0.13
20. 'W. Ama.'	NF	Cha	1036	945	767	603	838	*	-0.10	0.02	1003	889	607	531	758	*	-0.07	0.11
21. 'W. Rojo'	NF	Cha	1713	1155	746	1050	1166	**	0.15	0.12	1605	921	592	937	1014	**	0.32	0.08
22. 'A. Palta'	NF	Adg	1682	1434	1050	1146	1328		0.06	-0.01	1430	1261	898	1003	1148		-0.14	-0.04
23. 'T. Waq.'	NF	Adg	1566	1435	1114	1263	1345		0.07	-0.08	1286	1172	964	1001	1106		-0.14	-0.08
24. 'Peruan.'	NF	Gon	1201	677	620	691	797	**	0.08	0.18	1012	551	528	559	663	**	0.20	0.14
25. 'Runtu'	NF	Gon	1045	954	849	747	899		-0.03	-0.04	806	844	627	543	705		-0.17	-0.01
26. 'Ayram.'	NF	Adg	1446	1052	814	806	1030	*	0.02	0.09	1299	914	655	650	880	**	0.12	0.12
27. 'P. Lagar.'	NF	Adg	1767	1257	818	1089	1233	**	0.13	0.10	1616	1140	680	1034	1118	**	0.37	0.03
28. 'P. Makin'	NF	Adg	933	705	784	729	788		0.07	-0.07	731	508	635	642	629		-0.24	-0.14
29. 'Sullu'	NF	Adg	1557	1264	1231	868	1230	*	-0.07	0.03	1406	1074	994	795	1067		0.16	0.05
30. 'Runtus'	NF	Gon	1040	672	599	620	733	*	0.07	0.11	751	558	405	501	554	*	0.21	0.01
31. 'Ipillu'	NF	Adg	1219	1268	1118	1621	1307		0.16	-0.26	1003	1032	928	998	990		-0.22	-0.22
		XE	1262	1071	869	830	1088				1053	904	703	685	836			
		IPCA_1	0.12	-0.37	-0.28	0.53					-0.36	0.43	0.35	-0.43				
		IPCA_2	0.57	-0.12	-0.15	-0.29					0.52	0.00	-0.05	-0.47				

** p>0.01; * p>0.05; C.C.= cultivar category; [a]= significance for ANOVA

Table 4.16: Means of the cumulative variables, environments (E) and genotypes (G), and environment and genotype coordinates of the first and second IPCA axis

Genotype	C.C.	Species	Total number of tubers / plant								Marketable number of tubers / plant							
			F1	F2	F3	F4	XG	Sig.[a]	IPCA_1	IPCA_2	F1	F2	F3	F4	XG	Sig.[a]	IPCA_1	IPCA_2
1. 'Chingos'	NF	Stn	19	18	20	14	18		-0.25	0.02	11	10	12	8	10		-0.03	-0.24
2. 'Leona'	NF	Adg	41	39	51	68	50	**	1.09	0.02	4	10	11	7	8	**	-0.63	0.00
3. 'Qeqorani'	NF	Stn	18	20	18	15	18		-0.22	-0.02	12	13	10	8	10		0.00	-0.16
4. 'C. Runtu'	NF	Gon	18	13	15	14	15		-0.06	0.39	12.	8	8	8	9		0.40	-0.17
5. 'M. Taruna'	NF	Stn	14	19	15	12	15		-0.23	-0.18	9	11	10	7	9		-0.20	-0.07
6. CIP-700234	NF	Adg	12	15	19	13	15		0.00	-0.30	10	10	10	8	9		0.00	-0.03
7. 'M. Bonita'	IMP	Hybrid	10	8	10	7	9		-0.09	0.15	5	4	7	3	5	*	-0.11	-0.45
8. 'Mariva'	IMP	Hybrid	16	16	14	9	14	**	-0.47	0.07	10	10	10	5	9	**	-0.08	-0.49
9. 'Perricholi'	IMP	Hybrid	17	16	15	13	15		-0.14	0.14	12	9	8	8	9		0.34	-0.08
10. 'Huaman.'	NF	Cha	20	24	23	19	22		-0.12	-0.15	8	13	10	9	10		-0.33	0.19
11. 'Camot.'	NF	Gon	19	18	20	18	19		0.01	0.09	9	9	11	10	10		-0.07	0.00
12. 'S. Largo'	NF	Adg	19	17	21	17	18		0.02	0.05	11	10	12	10	11		0.05	-0.12
13. 'Tarmeña'	NF	Adg	37	25	22	24	27	**	-0.24	0.74	10	12	9	10	10		0.00	0.24
14. 'Q. Papa'	NF	Adg	18	11	15	15	15	*	0.11	0.49	11	6	8	9	9	*	0.49	-0.05
15. 'Y. Man.'	NB	Adg	17	17	21	22	19		0.38	-0.04	11	9	11	13	11		0.20	0.17
16. 'Y. Siri'	NB	Juz	11	17	14	13	14		-0.06	-0.32	7	12	9	8	9		-0.28	0.15
17. 'Q. Siri'	NB	Cur	12	21	21	13	17	**	-0.19	-0.61	9	12	9	8	9		-0.17	0.02
18. 'Puqya'	NF	Stn	19	21	22	17	20		-0.15	-0.12	10	12	11	10	11		-0.15	0.06
19. 'A. Suytu'	NF	Cha	18	21	18	25	21	*	0.41	0.00	10	11	9	13	11		0.16	0.45
20. 'W. Ama.'	NF	Cha	10	12	12	12	11		0.13	-0.07	8	11	7	6	8	*	-0.07	0.07
21. 'W. Rojo'	NF	Cha	16	19	16	18	17		0.08	-0.04	11	10	7	11	10		0.32	0.36
22. 'A. Palta'	NF	Adg	19	22	27	23	23		0.21	-0.23	11	14	15	14	14		-0.14	0.17
23. 'T. Waq.'	NF	Adg	24	24	25	27	25		0.18	0.05	13	15	15	13	14		-0.14	0.05
24. 'Peruan.'	NF	Gon	18	18	18	17	18		-0.02	0.07	11	10	9	9	10		0.20	-0.03
25. 'Runtu'	NF	Gon	19	20	24	15	19		-0.18	-0.15	9	10	12	8	10		-0.17	-0.20
26. 'Ayram.'	NF	Adg	16	18	21	19	19		0.21	-0.19	11	10	11	10	11		0.12	-0.03
27. 'P. Lagar.'	NF	Adg	16	13	15	14	14		0.03	0.20	11	9	7	10	9		0.37	0.21
28. 'P. Makin'	NF	Adg	18	16	20	14	17		-0.12	0.01	7	8	13	9	9	*	-0.24	-0.09
29. 'Sullu'	NF	Adg	13	14	13	12	13		-0.06	0.01	10	8	9	7	9		0.16	-0.20
30. 'Runtus'	NF	Gon	15	14	14	13	14		-0.02	0.14	9	7	7	6	7		0.21	-0.21
31. 'Ipillu'	NF	Adg	29	35	35	26	31		-0.24	-0.24	12	18	15	17	15	*	-0.22	0.47
		XE	18	19	20	18	19			10	10	10	9	10				
		IPCA_1	-0.55	-0.66	-0.05	1.26				0.96	-0.64	-0.64	0.32					
		IPCA_2	1.08	-0.63	-056	0.12				-0.54	0.24	-0.60	0.90					

** p>0.01; * p>0.05; C.C.= cultivar category; [a]= significance for ANOVA

Figure 4.7: Biplot for total tuber yield per plant using genotypic and environmental scores (31 potato cultivars / 4 environments)

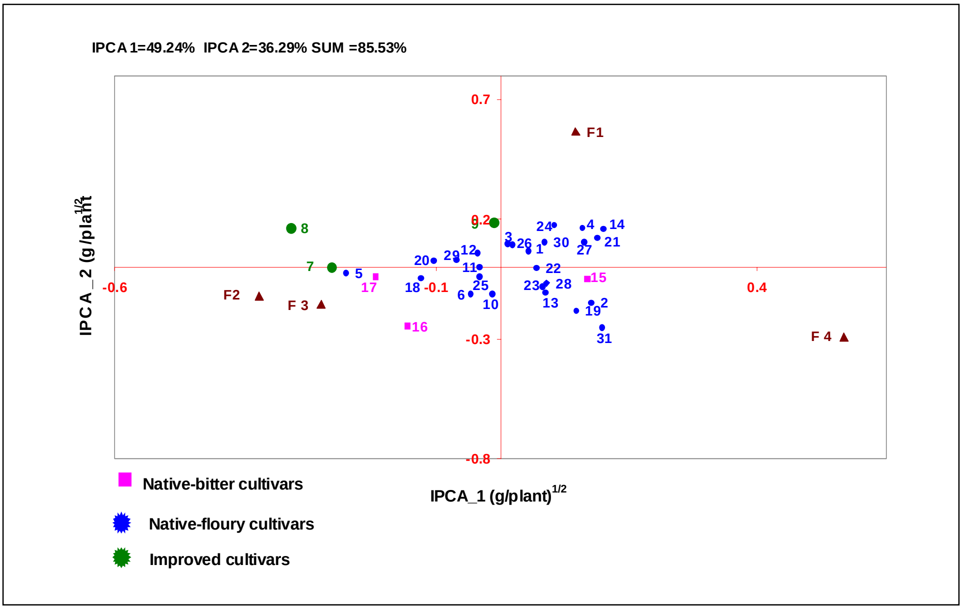
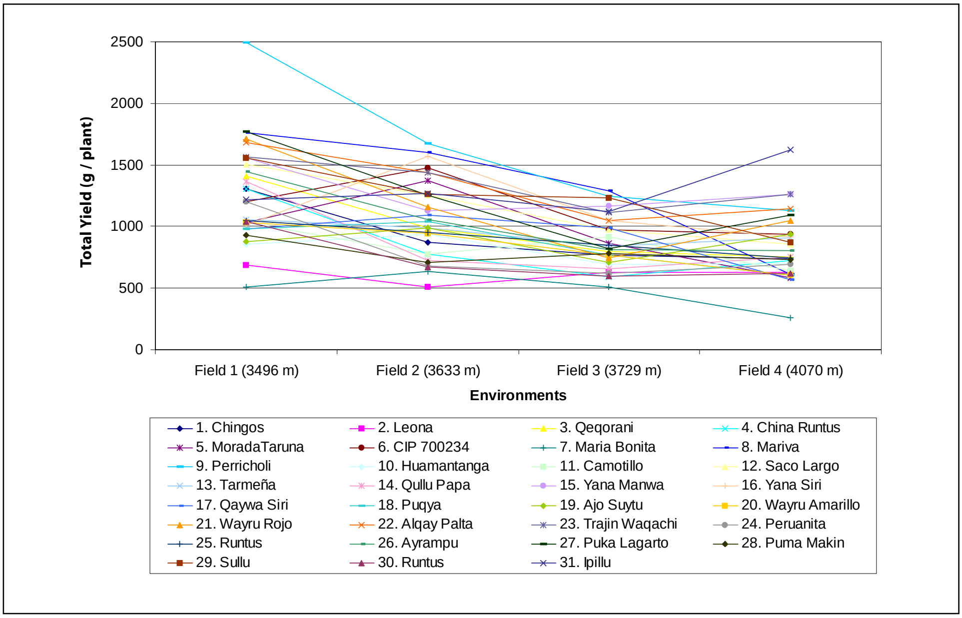


Figure 4.8: Total yield (g / plant) for all cultivars across four environments



4.4 Discussion and conclusions

Annual temporal variation of tasks and labor demand are primarily a response and adaptation to the rain-fed character and climate extremes of high-altitude cropping in the Andes. The main season (*qatun tarpuy*) is well synchronized to the seasonal nature of the climate and the secondary season (*michka*) is an additional response to the need for fresh produce during a period of relative food scarcity and high-value income. Andean tillage systems have in part evolved as an adaptive strategy to the existence of a single predominant cropping season with time-fixed labor demands for specific tasks. Footplough-based soil preparation of fallow land is labor demanding, but the combination of 3 different tillage systems, each with different temporal labor distribution patterns and peaks, allow potato farmers to respond more flexibly to a potential conflict between demand versus availability of labor and therefore manage their genetic and other resources more optimally.

Rationales other than the spread of labor alone are also likely to constitute important considerations for farmers when choosing between the different tillage systems that make use of the *chakitaklla*. The different tillage systems are modestly associated with specific cultivar categories and their typical management regimes, such as *barbecho* tillage with the cultivation of improved and commercial native-floury cultivars under semi-intensive management and *chiwa* tillage with the cultivation of native-bitter and mixed native-floury cultivars under semi-organic management. Even though this research did not explore adaptationist rationales of footplough-based tillage systems beyond the spread of labor and use of specific cultivar categories, it is likely that diverse factors influence farmer decision making when choosing between tillage systems. Indeed, farmers reported potatoes planted with *chacmeo* to develop particularly well under conditions of bad drainage or excessive rainfall and *chiwa* stands to resist prolonged droughts. This suggests that the different tillage systems are also part of an overall risk mitigation strategy in a generally extreme and unpredictable cropping environment.

Differential management of infraspecific diversity is one among multiple factors underlying the logic of field scattering. First, different cultivar categories occupy different fields. This is a consequence of the different vegetative periods, management requirements and end-uses these cultivar categories have. Second, at a more fine-grained level, individual cultivars and mixtures are also physically separated in different fields resulting in the uneven distribution of genetic diversity across the agricultural landscape. Again, differential management and diverse end-uses have their part as numerous households destine uniform stands of native-floury cultivars produced with external inputs for sales while preferring mixed stands of organically produced native-floury cultivars for home consumption. However, this does not explain why high levels of cultivar diversity within fields are concentrated between 3,851 and 4,150 m of altitude. The GxE experiment showed that most native cultivars are versatile and that the notion of tailored niche adaptation of diverse cultivars is generally weakly supported by field data. Weather extremes, particularly of hails and frosts, are frequent at the altitudinal range where high levels of cultivar diversity are concentrated. This alludes to the possibility that high levels of cultivar diversity are employed to confront abiotic stress.

Native-floury cultivars commonly occupy more scattered fields and total cropping area compared to native-bitter and improved cultivars. However, considerable differences concerning the number of scattered fields, total potato cropping area, and levels of within-field cultivar diversity managed by households exist within and between communities. Differences between communities are likely related to numerous factors, including overall land availability, relative population densities, levels of market integration, and tradition of potato cultivation while factors underlying differences within communities are probably as multifaceted and based on a household's ability to mobilize and access resources such as labor, land and financial capital. No direct relation exists between the intensity of field scattering and overall richness of infraspecific diversity.

The three cultivar categories, each represented by a different set of cultivated potato species, do not occupy specific agroecological niches that are sharply separated by altitude (so-called altitudinal belts). To the contrary, their field and areal distribution patterns show considerable overlap even though improved cultivars have an extensive altitudinal distribution pattern, native-bitter cultivars occupy a relatively restricted altitudinal range, and native-floury cultivars represent an intermediate scenario. Differences between the altitudinal medians for areal distribution are modest, particularly for the categories of improved and native-floury cultivars which are only separated by fifty meters and not hundreds of meters as frequently thought. This reality fits Zimmerer's (1998, 1999) model of overlapping patchworks which proposes that patchiness and altitudinal overlap are shaped by broad adaptability of the potato and multifaceted cropping rationales of farmers. Improved cultivars in Huancavelica are cultivated at extremely high altitudes with their median for areal distribution between 3,951 and 4,000 m. This is much higher than generally reported for this cultivar category. Its is likely that farmers are taking higher risks by pushing improved cultivars upwards in response to internal and external socioeconomic tendencies such as increased human population densities and a growing need for cash income. Additionally, climate change may facilitate the cultivation of improved cultivars at ever higher altitudes.

The argument of narrow niche adaptation as a principal driving force behind farmer-driven *in-situ* conservation of infraspecific diversity within altitude-differentiated fields is not supported by the results of the genotype by environment (GxE) trial data. Even though some genotypes showed significant production differences between environments, none of them showed tailored adaptation. Indeed, with the notable exception of the improved cultivar *Maria Bonita*, all genotypes in all environments produced more than half a kilo per plant. A gradual and significant total yield decline by increased altitude was evident for 35.5% of the genotypes, yet most genotypes were versatile. The argument of narrow adaptation of cultivars is also contradicted by common farmer practices such as the cultivation of mixed cultivar stands (*chaqru*), crop rotation design (chapter 5) and seed flows across distinct environments (chapter 6), all of which suppose broad adaptability and medium to high levels of genotype by environment (GxE) insensitivity. An improved cultivar such as *Perricholi*, even though significantly more productive at low altitudes, still produced an appreciable yield of well over one kilogram per plant at 4,070 m of altitude. The native-bitter cultivars *Yana Siri* and *Qaywa Siri* produced significantly more at low altitudes. So, native-bitter cultivars which are generally encountered at extremely high altitudes do in fact produce well at low altitudes.

The regionally well-known native-floury cultivar *Puqya* provides an exemplary perspective on genotype by environmental management practiced by Andean farmers. The cultivar is known to be rustic and tolerate hail and frost. Total yield of *Puqya* significantly fluctuated by environment showing the lowest yield level at the highest altitude. So why do farmers go against apparent logic and generally plant *Puqya* at altitudes above 4,000 m? It seems evident that farmers take advantage of tolerance and resistance traits by planting the most rustic genotypes in the highest-risk environments. Farmers recognize and consciously exploit tolerance and resistance traits in environments where these characters can be useful. Cultivar mixtures (*chaqru*) are purposefully installed in high risk environments because of their combined tolerance and resistance to environmental extremes. Such mixtures are not less frequently grown at low altitudes because they are not adapted and thus do not produce. Rather, it comes back to their combined rusticity and comparative advantage in a particular environment. Improved cultivars at low altitude often do better because of bred-in resistance to late blight and earliness which helps these cultivars to partially "escape" severe disease pressure. So, farmers may manage genotype by environmental adaptation. Yet, not for maximum yield output nor for fine-grained niche adaptation, but rather for yield stability or for a genotype's ability to produce under extreme conditions.

5 Land use and potato genetic resources in Huancavelica, central Peru[1]

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Key words: land use tendencies, rotation designs, sectoral fallow systems, infraspecific diversity, *in-situ* conservation, Huancavelica

Abstract

Three specific dimensions of potato land use were researched in order to gain insights into possible contemporary changes affecting the *in-situ* conservation of potato genetic resources: land use tendencies, rotation designs and their intensity, and sectoral fallowing systems. The main research method involved participatory cartography combined with in-depth consultation through interviews and focus group meetings with members of 8 Andean highland communities.

Land use tendencies between 1995 and 2005 shows that the total cropping area dedicated to improved cultivars has grown fast while the area reserved for native-floury and native-bitter cultivars has remained more or less stable. Reduced fallow periods for existing fields and the gradual incorporating of high-altitude virgin pasture lands sustain areal growth. While areas of improved cultivars are proportionally growing fastest at extremely high altitudes between 3,900 and 4,350 m of altitude, overall cropping intensity or fallowing rates are inversely related to altitude. No evidence of a straightforward replacement of one cultivar category by another was found. Inquiry into the dynamics of sectoral fallow systems over a 30 year period evidences the gradual disintegration and abandonment of these systems rich in cultivar diversity. Where sectoral rotation designs survive local innovations have been adopted.

5.1 Introduction

A major difference between the *in-situ* conservation of wild *Solanum* populations and cultivated potato genetic resources resides in the fact that the latter needs to be used in order

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to maintain viable populations. Viability refers to a minimal population size needed in terms of the area dedicated to the different potato cultivars categories (native-floury, native-bitter and improved) and individual cultivars. Agricultural land use involves the human modification of uncultivated and cultivated areas for the purpose of food production. This paper will deal with three specific components of potato land use in this crop's center of origin: land use tendencies, rotation designs and their intensity, and sectoral fallowing systems. These selected dimensions of land use were researched in order to obtain a better understanding of the medium term temporal-spatial dynamics of potato genetic resources.

The contemporary Andean landscape is highly worked and shaped by human activity. Pre-Columbian Indians managed more landscapes than previously thought, including areas which are nowadays perceived as untouched or wild (Mann, 2006). Changes of Andean land use have historically been driven by diverse overarching processes such as politics, climate change and demographics (Cook, 1981; Dillehay and Kolota, 2004; Hastorf and Johannessen, 1993; Seltzer and Hastorf, 1990; Young and Lipton, 2006). These same processes, although notably different in character, remain important drivers for agricultural and land use change today. Yet, little is known about how infraspecific diversity is affected by changes in agriculture (Brush, 2004, p. 105).

Land use tendencies concern temporal and spatial (re)arrangements of cropping areas, including the area dedicated to a particular crop or cultivar category and the incorporation or abandonment of agricultural land. Data sets and studies of land use tendencies do generally not allow for inference about infraspecific diversity, altitudinal ranges and intra-provincial scales. National, departmental and provincial potato statistics and time-series are available for area and yield (see FAO, 2008; INEI, 1994, 2004; OIA-MINAG, 1998; Rubina and Barreda, 2000). However, these are of little value for inferences about genetic variability within the crop. Knowledge of higher-resolution land use tendencies, such as the cropping area dedicated to cultivar categories, potentially allows for the identification of trends that can either be favorable or detrimental for the sustainable *in-situ* conservation of potato.

Crop rotation designs can either be based on household or communal decision-making and tend to follow a dynamic logic that takes into account such factors as crop-crop and crop-livestock ecological complementarities, subsistence demand for foods and fodder, market trends, among other factors. Indeed, tradeoffs between diverse environmental and economic indicators generally shape farmer decision making concerning crop sequences and fallowing. Characterization of crop rotations can provide valuable insights into designs (crop sequences and their frequencies) and land-use intensity (fallowing rates) to which potato genetic resources are subjected.

The origin of sectoral fallowing systems in the Andes is disputed. Erickson (2000, pp. 326-327) considers the system to be pre-Columbian based on archeological evidence while Denevan (2002, p.45) suggests a colonial origin. Campbell and Godoy (1986, p. 325) and Godoy (1991, p. 396) have suggested that Andean common field agriculture has pre-Hispanic roots and undergone modifications after the Spanish conquest. Biological advantages of sectoral fallowing systems include the recuperation of soil fertility, pest and disease control, risk avoidance, and the availability of pasture during fallow periods (Hervé *et al.*, 1994; Pestalozzi, 2000). Social advantages include the reduction of labor time demands[2] for land use and intergenerational access to land (Godoy, 1991; Zimmerer, 2002). An additional function of the sectoral fallowing system is the (informal) delimitation and control of community boundaries (Allen, 2002).

Sectoral fallow systems are characterized by predefined sectors within a community (6-12 sectors typically constitute a circuit), a common rotation design defined by the community with

[2] Godoy (1991, p. 409) points out that it is not mere coincidence that common field agriculture attained its most complex form and survived the longest in the same regions that faced heaviest labor-tribute liabilities during the colonial era, such as the department of Huancavelica, Peru.

a predefined crop for an entire sector, intermixed household assigned plots within a particular sector, regulation and supervision of access by the community[3], and prolonged fallow after cultivation with use as communal pastureland. Additionally, sectoral fallow systems, commonly called *laymis*[4] in central Peru, are production spaces recognized for their rich content of diverse potato cultivars. They are "diversity hotspots" as farmers traditionally use these spaces to plant mixed cultivar stands (*chaqru*). Native potatoes are typically the initial crop to break the fallowing period and occupy the land during the first year's cropping cycle (Orlove and Godoy, 1986). Sectoral fallow systems are increasingly abandoned as a consequence of socioeconomic change and uncoordinated intensification (Mayer, 1985; Zimmerer, 2002), a process which possibly implies the gradual disintegration of important potato "diversity hotspots". Little is known about this disintegration, potential adaptations and effects on potato cultivar conservation.

The purpose of this article is to investigate land use of potato genetic resources in Peru's central Andes. First, land use tendencies for an 11-year time span with particular emphasis on the dynamics of cropping areas dedicated to each of three cultivar categories. Second, contemporary crop rotation designs and their intensity for each of three cultivar categories. Third, long-term changes for a 30-year timeframe for sectoral fallow systems.

5.2 Materials and methods

This research was conducted between 2005 and 2006 in 8 communities following a north-south transect through the department of Huancavelica, central Peru (chapter 1). Land use tendencies and rotation designs were researched applying participatory cartography, also commonly referred to as participatory GIS (Bussink, 2003; Voss *et al.*, 2004), with printed poster-size high-resolution Quickbird satellite images for each community (table 5.1). Cartography and visual representation can be useful research tools in human ecology (Zimmerer, 1999, p. 153) and Geographical Information Systems (GIS) platforms provide an adequate framework to systematically document local geospatial and temporal-change data (Chapin and Threlkeld, 2001; Craig *et al.*, 2002; Tripathi and Bhattarya, 2004). Household members older than 27 years of age identified their fields on the base maps. The crop species and potato cultivar contents by field were recorded for an 11-year period (1995-2005) based on the household's collective memory. Field identification and contents were cross-checked using focus group meetings, site visits, triangulation, and repeat inquiries. A total of 196 households participated in the exercise (39.8% of the total population). A total of 4,343 fields and their 1995-2005 crop contents were mapped (table 5.1). The data was digitalized using MS-access, Arc-view and Arc-info software, and stored at the International Potato Center's GIS-laboratory.

The evolution over a 30-year time-span (1975-2005) of sectoral fallow systems was investigated through participatory cartography and in-depth consultation through interviews and focus group meetings with community members older than 50 years of age. Former and contemporary sectoral fallow systems were mapped with community member and authorities through site visits and walks along boundaries. Georeferenced sectoral fallow systems were visualized using Arc-view and Arc-info software. Processes of change, management and adaptive innovation were documented building case studies for each of the research communities.

[3] Generally the community assembly takes decisions concerning dates of planting and harvesting, access of newly founded families, etc. A special type of supervision is done by assembly-appointed guards in charge of supervising fields, preventing animals from entering fields, guarding against theft, levying fines, and performing practices to prevent damage from hails or frosts. These guards generally receive payment in kind and are known as *inspectores* (Chopcca) or *varayoqs* (Pongos) in Huancavelica, and *maranis*, *arariwas*, *camayoqs*, *pachacas*, *campos* or *muyucamas* in other parts of the indigenous Andes.

[4] Sectoral fallowing systems are also known by other diverse regional names, including *aisha*, *aynoqa(s)*, *chutta(s)*, *manda(s)*, *muyuy(s)*, *surt'i(s)* or *suerte(s)*, *suyu(s)*, and *turno(s)*; see Cahuana *et al.*, 2002; De Haan, 2000; Erickson, 2000; Fernández, 1990; Godoy, 1988; Wiegers *et al.*, 1999; Zimmerer, 1999, 2002.

Table 5.1: Sample sizes obtained with participatory cartography

Community	Transect	Sample Size (n)		
		Households	Fields	Fields / household
Huayta Corral	North	28	558	19
Tupac Amaru	North	30	796	27
Villa Hermosa	Center	30	832	28
Pucara	Center	17	370	21
Dos de Mayo	Center east	20	364	18
Libertadores	Center east	30	655	22
Pongos Grande	South	20	414	21
Allato	South	21	354	17
TOTAL		196	4343	22

5.3 Results

5.3.1 Land-use tendencies

The total annual area dedicated to selected crop species, particularly potatoes, cereals, legumes and Andean root and tuber crops (ARTC's), increased steadily between 1995 and 2005 (table 5.2). Additionally, the total area of cultivated pasture and trees also expanded. The total potato cropping area increased by 63% between 1995 and 2005. The 88% areal increase of cereals particularly involved barley (*Hordeum vulgare*) while the 242% areal increase of legumes was spearheaded by tarwi (*Lupinus mutabilis*) and to a lesser extent fababeans (*Vicia faba*). The total area dedicated to ARTC's had grown spectacularly with an areal increase of 1362%. Increased market demand for maca (*Lepidium meyenii*) was the main driver behind this expansion. Forestations with eucalyptus (*Eucalyptus globulus*), especially on eroded soils, increased considerably (352%) and a similar tendency was also notable for cultivated pasture, particular oats (*Avena sativa*), with a total increase in area of 342%. This gradual but steady expansion of the before mentioned species was possible because of reduced fallow and the incorporation of previously uncultivated native pasture lands (table 5.2). The later implies a gradual expansion of the agricultural frontier towards higher altitudes where soils were previously untilled. Intensified land use allows for fewer years for land to recover fertility. Indeed, growing areas of barley, a crop well adapted to poor soils, and trees suggest that the overall soil fertility may be declining.

The areal dynamics of the potato crop is characterized by a more or less stable area dedicated to native-floury and native-bitter cultivars, and a steady increase of the total area dedicated to improved cultivars (table 5.3). Native-floury cultivars proportionally occupied most of the total potato cropping area: 72.7% in 1995 and 64.5% in 2005. A sharp increase in the area of native-floury cultivars can be observed for 2005. The expansion of improved cultivars was considerable with an overall areal increase of 182%.

Table 5.2: Tendencies for crop areal distribution in 8 communities (1995-2005; n= 196[1] / 4343[2])

Field content	Cropping Area / Year – Hectares										
	95	96	97	98	99	00	01	02	03	04	05
Potato	71.8	81.7	90.2	81.2	93.5	97.2	95.4	83.6	95.2	91.3	117.1
Cereals	47.8	55.5	67.5	73.5	71.1	74.5	79.8	80.3	70.0	79.2	89.8
Legumes	11.0	12.0	18.5	17.5	20.8	24.1	17.8	21.8	19.1	24.3	37.6
Vegetables	0.2	0.4	0.6	0.5	0.6	1.0	1.4	1.7	1.3	1.1	1.0
ARTC's (*)	2.9	5.5	4.8	7.9	8.2	13.9	14.6	18.7	20.2	33.3	42.4
Cult. pasture	6.9	5.7	5.8	7.0	7.1	9.5	12.4	13.6	17.1	24.7	30.5
Forestry (trees)	2.3	2.6	2.7	3.1	3.1	3.4	4.5	6.4	7.2	8.2	10.4
Fallow land	441.9	426.7	400.8	404.0	403.4	388.7	389.6	401.3	411.4	389.5	338.9
Native pastures	222.1	216.0	214.2	210.5	197.5	193.1	190.7	178.0	163.6	149.2	133.3
Others (**)	2.0	2.8	3.8	3.7	3.6	3.5	2.7	3.5	3.8	8.1	7.9

[1]= households; [2]=fields; *= Andean root and tuber crops, dominated by maca (*Lepidium meyenii*); **= associated crops

Table 5.3: Tendencies for the areal distribution of potato cultivar categories in 8 communities (1995-2005; n= 196[1] / 4343[2])

Field content	Cropping Area / Year – Hectares										
	95	96	97	98	99	00	01	02	03	04	05
Native-floury cvs	52.2	52.5	54.5	50.7	54.8	60.3	61.7	47.6	56.3	54.8	75.5
Native-bitter cvs	8.3	15.2	11.9	11.8	12.7	10.5	12.3	9.8	8.3	7.6	9.7
Improved cvs	11.3	14.0	23.8	18.7	26.0	26.4	21.4	26.2	30.6	28.9	31.9

[1]= households; [2]=fields; cvs = cultivars

Comparison for specific potato cultivars shows that selected commercial cultivars have increased in area (table 5.4), particularly the improved cultivar Yungay (240%) and commercial native-floury cultivar Peruanita (512%). The cropping area dedicated to other cultivars has remained more or less stable between 1995 and 2005. The time series for the area dedicated to genetically diverse cultivar mixtures (*chaqru*) shows no evidence of replacement or decline. Although the area of *chaqru* fluctuated between 1995 and 2005, it had a general tendency to expand between 2002 and 2005.

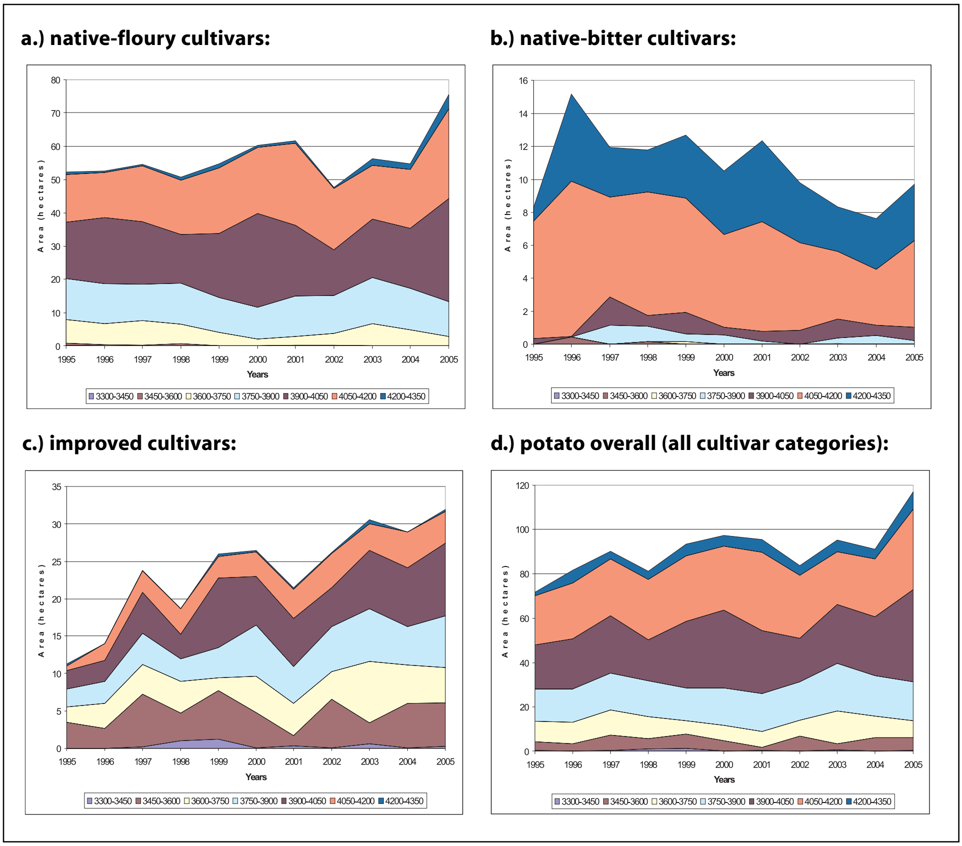
Table 5.4: Tendencies for the areal distribution of specific potato cultivars in 8 communities (1995-2005; n= 196[1])

Cultivar	Category	Cropping Area / Year – Hectares										
		95	96	97	98	99	00	01	02	03	04	05
'Peruanita'	Native-floury	1.7	2.5	0.9	2.4	3.3	4.8	7.8	7.0	8.7	9.6	10.4
'Runtus'	Native-floury	0.1	0.2	0.1	0.2	0.6	0.5	0.1	0.8	1.5	0.9	0.9
'Puqya'	Native-floury	1.2	0.9	2.6	2.3	1.7	1.3	1.8	0.3	1.2	1.2	2.0
'Camotillo'	Native-floury	1.9	3.2	2.0	2.0	3.0	3.6	4.1	2.3	2.8	2.9	3.4
Chaqru (*)	Native-floury	41.9	38.3	40.0	35.8	37.7	41.1	37.9	29.2	31.4	33.4	49.4
'Yuraq Siri'	Native-bitter	7.4	11.2	9.2	8.1	10.9	9.0	11.2	9.0	5.8	5.5	6.3
'Y. Manwa'	Native-bitter	0.6	3.1	2.5	3.5	1.8	1.3	1.1	0.8	1.5	1.9	2.6
'Canchan'	Improved	0.6	0.1	0.8	0.4	1.0	1.0	1.2	3.1	2.5	1.5	1.9
'Yungay'	Improved	6.2	7.0	15.1	10.5	15.9	15.6	10.6	14.5	18.9	17.6	21.1

[1]= households; * = complete cultivar mixtures

When mapping the yearly cropping area of potato and its 3 cultivar categories by altitudinal ranges of 150 meters it becomes evident that areas, especially of improved cultivars, are proportionally increasing more rapidly at high altitudes; particularly so between 3,900 and 4,350 meters above sea level (fig. 5.1). The overall potato cropping area increased by 63% between 1995 and 2005; yet, rates of increase were proportionally higher at increased altitudes: 110% between 3,900-4,050 m, 65% between 4,050-4,200 m, and 339% between 4,200-4,350 m. This rapid increase at high altitudes is particularly fueled by improved cultivars. The yearly proportion of native-floury cultivars by altitudinal belts has been relatively constant between 1995 and 2004 with a sharp areal increase between 3,900 and 4,350 m in 2005. In 2005 the total area of native-bitter cultivars was similar to 1995 with the notable difference that also native-bitter cultivars had proportionally gone up in altitude. Figure 5.1 clearly shows that improved cultivars have ample and native-bitter cultivars restricted altitudinal distribution patterns. The data also shows that there is considerable overlap between the altitudinal belts where the 3 cultivar categories are grown and that they are certainly not sharply separated by altitude.

Figure 5.1: Tendencies for total area planted with cultivar categories by altitudinal range (150 m intervals; n= 196[1] / 3514[2])



[1] = households; [2] =fields containing potato

5.3.2 Rotation designs and intensity

Farmers in Huancavelica manage many different crop rotation designs involving the potato crop (table 5.5). A total of 84, 21 and 93 different rotation designs were recorded for native-floury, native-bitter and improved cultivars respectively. It is common practice to start cropping cycles with potato as a fallow breaker. Designs with grain crops are common for all cultivar categories. Between 54.6% and 61.8% of the fields, depending on the specific cultivar category, either included barley or oats after potato and before fallow.

Table 5.5: Most frequent rotation designs by cultivar category

Native-floury cultivars (n=1531[1])		Native-bitter cultivars (n=314[1])		Improved cultivars (n=656[1])	
Rotation designs	**%**	**Rotation designs**	**%**	**Rotation designs**	**%**
F-NFC-BA-F	41.0	F-NBC-OA-F	39.5	F-IC-BA-F	40.1
F-NFC-OA-F	13.6	F-NBC-BA-F	22.3	F-IC-BA-BA-F	14.9
F-NFC-F	8.6	F-NBC-F	20.4	F-IC-FB-BA-F	7.8
F-NFC-FB-F	4.4	F-NBC-OA-OA-F	4.5	F-IC-F	7.6
F-NFC-BA-BA-F	3.2	F-NBC-NBC-F	2.2	F-IC-FB-F	3.8
F-NFC-FB-BA-F	2.5	F-NBC-BA-OA-F	1.9	F-IC-OA-F	3.0
F-NFC-NFC-F	1.8	F-NBC-MA-F	1.6	F-IC-BA-FB-F	1.5
F-NFC-MA-F	1.7	F-OA-NBC-F	1.0	F-IC-BA-OA-F	0.9
F-NFC-BA-FB-F	1.5	F-NBC-OA-BA-F	1.0	F-IC-MA-F	0.9
F-NFC-BA-OA-F	1.3	F-OA-MA-NBC-F	0.6	F-BA-IC-F	0.8
F-NFC-BA-TA-F	1.3	F-NBC-BA-BA-OA-F	0.6	F-IC-BA-FB-BA-F	0.8
Others	19.1	Others	4.4	Others	17.9

[1] = fields; BA= barley; F= fallow, FB= fababeans; IC= improved cultivars (potato); MA= maca (*Lepidium meyenii*); NBC= native-bitter cultivars (potato); NFC= native-floury cultivars (potato); OA= oats; TA= tarwi (*Lupinus mutabilis*)

Table 5.6 provides and overview of fallowing rates[5] by altitudinal range and cultivar category for all mapped fields containing potato (n=3514). The overall average fallowing rate for the potato crop in Huancavelica is 0.63, meaning that fields generally lay fallow for 6.3 years within a 10 year period (3.7 years of cultivation). Potato cropping regimes are more extensive at high altitudes as fallowing rates gradually increase. Fields containing improved cultivars have relatively low fallowing rates and are consequently cultivated more intensively compared to fields containing native-floury or native-bitter cultivars. Native-bitter cultivars are managed extensively and have high average fallowing rates compared to the other cultivar categories. Overall fallowing rates for potato also vary between communities with a minimum of 0.59 for Villa Hermosa and maximum of 0.70 for Pongos Grande. Villa Hermosa is increasingly densely populated and arable land per inhabitant is scarce while rotations in Pongos Grande are still defined by community authorities following a sectoral fallow circuit.

Most fields, independent of their altitudinal range, were exclusively dedicated to cropping sequences containing a single potato cultivar category (fig. 5.2 and 5.3). Overall, only 14.5% of fields had non-exclusive rotation sequences for the eleven-year period; that's to say these fields at different moments in time contained more than one of the potato cultivar categories. Depending on the altitudinal range, non-exclusivity for cultivar categories by field fluctuated between a minimum of 1.3% (3,451-3,600 m) and maximum of 22.2% (4,051-4,200 m). So, farmers

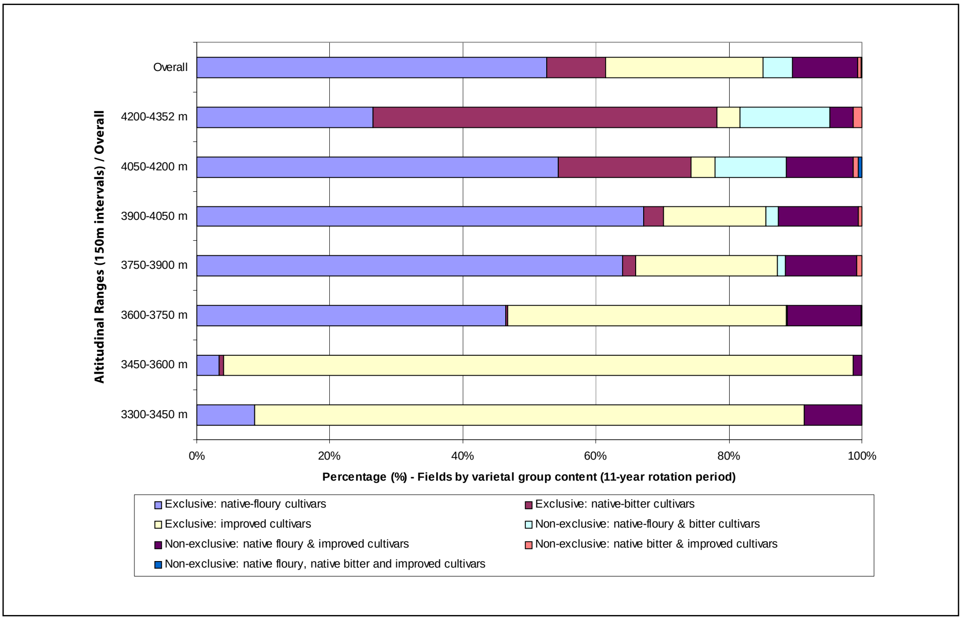
[5] $F.R.=\sum Yf/(\sum Yf+\sum Yc)$; F.R.=fallowing rate, Yf=years under fallow, Yc=years under cultivation.

predominantly dedicate fields exclusively to one of the three cultivar categories with increased rates of non-exclusivity at altitudes between 4,051 and 4,350 meter above sea level. This, in combination with the fact that farmers also manage exclusivity by altitudinal range, i.e. with more field-specific rotation sequences exclusively dedicated to improved cultivars at low altitudes and native-floury cultivars at high altitudes, indicates that farmers consciously manage field content by cultivar category.

Table 5.6: Fallowing rates for potato by altitudinal range and cultivar category (n=3514)

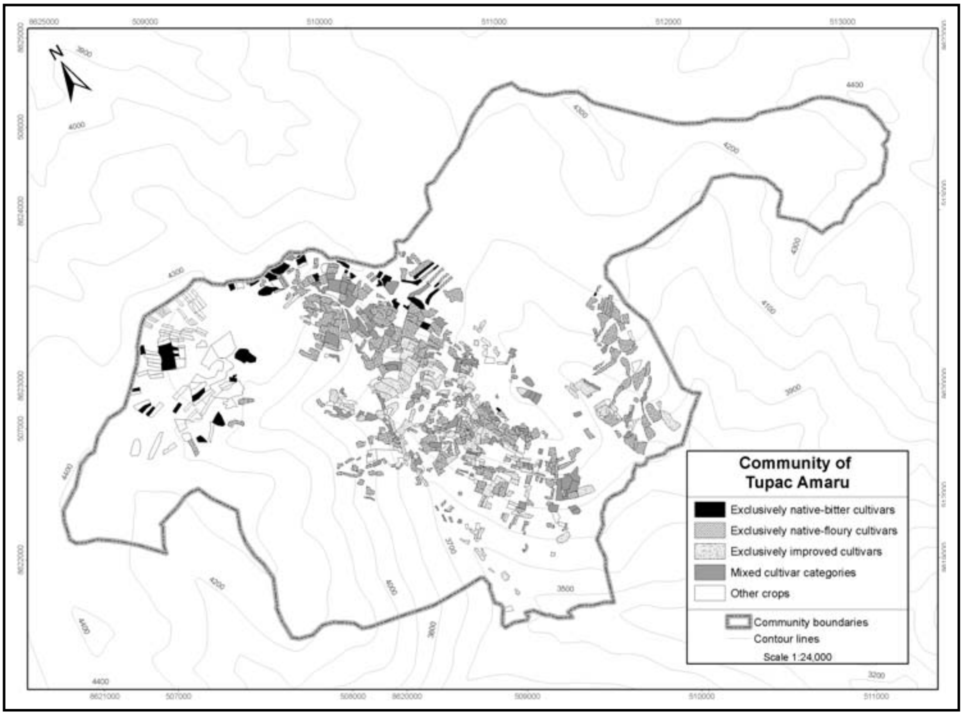
	Fallowing Rates			
	Average	SD (±)	Minimum	Maximum
Potato overall: 3,300-3,450 m	0.56	0.18	0.09	0.82
Potato overall: 3,450-3,600 m	0.61	0.14	0.09	0.91
Potato overall: 3,600-3,750 m	0.57	0.22	0	0.91
Potato overall: 3,750-3,900 m	0.61	0.19	0	0.91
Potato overall: 3,900-4,050 m	0.65	0.16	0	0.91
Potato overall: 4,050-4,200 m	0.66	0.15	0	0.91
Potato overall: 4,200-4,350 m	0.75	0.14	0.27	0.91
Potato: overall	0.63	0.17	0	0.91
Potato: floury cultivars	0.66	0.16	0	0.91
Potato: bitter cultivars	0.72	0.13	0.27	0.91
Potato: improved cultivars	0.59	0.20	0	0.91

Figure 5.2: Fields and their cultivar category content for an 11-year rotation sequence - exclusivity and non-exclusivity for cultivar category content by altitudinal range (n=3514[1])



[1] = fields containing potato

Figure 5.3: Fields and their cultivar category content for an 11-year rotation sequence - exclusivity / non-exclusivity profile map for the community of Tupac Amaru



5.3.3 Sectoral fallow systems

In 1975 all of the present-day research communities maintained sectoral fallow systems (*laymis*) with circuits consisting of 5 to 11 sectors. Communities such as Tupac Amaru, Dos de Mayo, Libertadores and Pongos Grande did not yet exist; at the time they were part of larger mother communities. Without exception, in each of the communities, mixed native potato cultivars were employed as fallow-breakers (table 5.7). Therefore sectors cropped immediately after prolonged fallow were "diversity hotspots" with all families planting their mixed cultivar stands (*chaqru*) predominantly in a single *laymi* sector. Thirty years later, in 2005, only one of the communities (Pongos Grande) maintains a sectoral fallow circuit consisting of 7 consecutive sectors and 1 flexible sector. The traditional annual communally-driven concentration of mixed cultivars in geographically delimited sectors shifted to patchier distribution patterns characterized by household decision-making.

The gradual disintegration of *laymis* was fueled by diverse socioeconomic changes, including population growth, separation from larger mother communities, tendencies favoring individualistic household-based management practices and a breakdown of communal decision-making structures. In all communities the process was the result of a combination of causes; each specific case was unique in its own. The communities of Tupac Amaru and Libertadores didn't adopt a new independent sectoral fallow system when they separated from their original mother communities (see box 5.1).

Table 5.7: Characteristics of the 1975 sectoral fallow systems and their posterior abandonment

Community	No. sectors (1975)	Rotation design (1975)	Year of definite abandonment	Selected causes of abandonment
Huayta Corral	5	F-NP-BA[1]-F	1995	Population growth
Tupac Amaru	11	F-NP-BA-F	1976	Separation from mother community
Villa Hermosa	10	F-NP-BA[2]-F	1985 -1988 [a]	Migration, rural violence
Pucara	8	F-NP-BA[2]-FB[1]-F	1990 [a]	Migration, rural violence
Dos de Mayo	9	F-NP-BA-F	1997	Population growth, separation from mother community
Libertadores (*)	-	n.a.	n.a.	n.a.
Pongos Grande	8	F-NP- BA[2]-F	**	n.a.
Allato	8	F-NP-BA[2]-F	1983	Population growth

F = fallow; NP = native potatoes; BA = barley; FB = fababeans; [1] = optional (in some sectors); [2] = sometimes altered with wheat, oats, olluco or fababeans (optional); [a] = flexible (non-sectoral) communal system property regime maintained to date; * = community was only founded in 1992 and its territory previously belonged to two different mother communities; ** = sectoral fallow system is maintained till date; n.a. = not applicable

Box 5.1: The case of the abandonment of Tupac Amaru's sectoral fallow system

The territory of the present-day community of Tupac Amaru occupies what used to be a single sector of a *laymi* circuit with a total of 11 sectors. The *laymi* sector used to be called Itaña Ccasa, meaning "stinging-nettle place", referring to the abundance of this species (*Cajophora* spp.). Before the land reforms initiated by the military government of General Juan Velasco Alvarado (1968-1975) the present-day community of Tupac Amaru was part of the hacienda "Santa Cruz de Esperanza" belonging to the *hacendado* family Loret de Mola. The hacienda managed the *laymi* circuit using the local families as a free source of labor. The rotation design started with native potatoes (year 1) followed by barley (year 2) and nine years of fallow. Native-bitter cultivars for *chuño* would be cultivated in a high-altitude sub-sector of a *laymi* sector while native-floury cultivars would be grown in a lower sub-sector. Local families were allowed to cultivate the steep and rocky sub-sectors within a *laymi* sector; fields would be assigned by the hacienda management.

After the land reforms Tupac Amaru became part of a state run cooperative (SAIS; *) which covered the ex-hacienda territory and maintained the *laymi* system. Frictions between different settlements were common during the initial period after the land reforms, but it was only in 1976, after the fall of the Velasco government, that Tupac Amaru became an independent community. Tupac Amaru claimed the territory of the Itaña Ccasa *laymi* sector, abandoning the wider *laymi* circuit which had included sectors that were distant from the newly formed community, dividing the land between local families wishing to reside in the new community. Nowadays fields are managed by individual households whom exercise autonomous decision-making over their property. Permanent pasture lands are still communally managed. The community also maintains three sectors which are cropped communally by means of *faenas* (communal working parties). Funds obtained through the sales of harvests from these communal fields are used by the community for the provision and maintenance of public services.

Source: interviews and focus groups 2004-2005; * = *Sociedad Agraria de Interés Social*, literally meaning "Agrarian Society of Social Interest" this was the main type of state cooperative installed in the Peruvian Andes between 1968 and 1975 (see Guillet, 1974, 1979; Long and Roberts, 1979)

The community of Dos de Mayo did establish a new *laymi* circuit when it got independent, but limited field space, reduced fallows and an increased population size caused the new system to be abandoned soon after the community gained autonomy in 1995. Population growth in Huayta Corral and Allato in combination with the desire of young families to increasingly invest resources in more intensive agricultural practices requiring individual usufruct rights triggered the abandonment of sectoral fallow systems. In Villa Hermosa and Allato young males, potential recruits for the army and the shining path, migrated to cities during the late 1980's. Remaining households from both communities clustered together, often along family ties, for increased security. Distanced *laymi* circuits were abandoned and when peace was reestablished rotations collectively managed by groups of families on communal land remained. Nowadays these communal areas do not follow a clear inter-sectoral rotation; in practice each area is treated as an independent unit.

Sectoral fallowing survived in the community Pongos Grande (box 5.2; fig. 5.4 and 5.5). Currently the community manages eight sectors: seven in a sectoral system and one flexibly (table 5.8). The adoption of several innovations was essential for the survival of the sectoral fallow system. These innovations were a response of the community to market demands and population growth. One of the innovations consists of more flexible crop compositions, especially for second year cropping cycles (table 5.8). Potato is still the common fallow-breaker to initiate the cropping cycle (year 1). However, stands of mixed native cultivars are nowadays accompanied by improved cultivars. The later have become predominant in the lower altitude sectors of *Carca Sunto*, *Habas Huaycco* and *Pampaway*. Depending on the specific *laymi* sector, second year crop choices are currently less strict and can include barley, oats, fababeans, olluco and peas. Only the high altitude *laymi* sectors of *Checchi Huaccta*, *Lima Ccocha*, *Totora Ccocha* and *Suytu Rumi* predominantly maintain the more traditional sequence of native potatoes, barley and fallow.

Box 5.2: The case of the survival of Pongos Grande's sectoral fallow system

The present-day community of Pongos Grande (*), founded in 1993, was part of a hacienda owned by the landowner Eduardo Larrauri and his four children before Peru's land reforms. A the time of the hacienda, before the year 1969, Pongos Grande hosted 6 sectors of a *laymi* circuit with a total of 11 sectors; five sectors were part of the neighboring community of Tuco. The 6 sectors within Pongos Grande's territory, in order of their rotation sequence, were: a. *Carca Sunto*, b. *Totora Ccocha*, c. *Limacc*, d. *Pucaccocha*, e. *Tambo Huaccta*, f. *Pampawaya*. This sectoral fallow system was managed by the hacienda owner and his *capataz* (**). The peasant households of Pongos Grande had to plant and maintain the crops for the hacienda. These were generally planted on the best soils. The four sectors *Carca Sunto*, *Totora Ccocha*, *Limacc* and *Pucaccocha* were only used for a single cropping cycle with native potatoes followed by ten years of fallow. The two sectors *Tambo Huaccta* and *Pampawaya* were cropped with potato (year 1), barley or olluco (year2), followed by nine years of fallow. The hacienda used the fallowing period to pasture livestock, while local households were allowed to cultivate temporarily assigned plots within a *laymi* sector and permanently assigned plots that had to be fenced in order to prevent the hacienda-owned cattle from doing damage.

After the land reforms Pongos Grande became part of the community and district of Ccochaccasa and a state promoted cooperative: SAIS Huancavelica. The previous hacienda *laymi* sectors became available for cultivation by local households and a new *laymi* circuit was defined excluding the sectors previously belonging to the community of Tuco and with two additional sectors within the territory belonging to Pongos. The new *laymi* system had 8 sectors: a. *Carca Sunto*, b. *Totora Ccocha*, c. *Suytu Rumi*, d. *Lima Ccocha*, e. *Checchi Huaccta*, f. *Tambo Huaccta*, g. *Habas Huaycco*, h. *Pampaway*. The rotation design in 1975 would start with native-floury potato cultivars (year 1) followed by barley and/or olluco (year 2) and 6 years of fallow. Before June 1993 all community members (*comuneros*) from the bigger community of Ccochaccasa had access to this *laymi* circuit. Yet, after separation from Ccochaccasa, a consequence of population growth and desire for independence, the *laymi* circuit only remained accessible for *comuneros* from Pongos Grande. The 8-sector *laymi* circuit, with modifications, is presently still maintained by the community of Pongos Grande.

Source: interviews and focus groups 2004-2005; * = Pongos derives from the term *pongo*, a common name for a servant working directly and obligatorily for the hacienda owner without salary or legal rights; ** = supervisor of the work to be delivered by common peasants for the hacienda

Figure 5.4: *Laymi* sectors of the neighboring communities of Pongos Grande and Allato - 1975

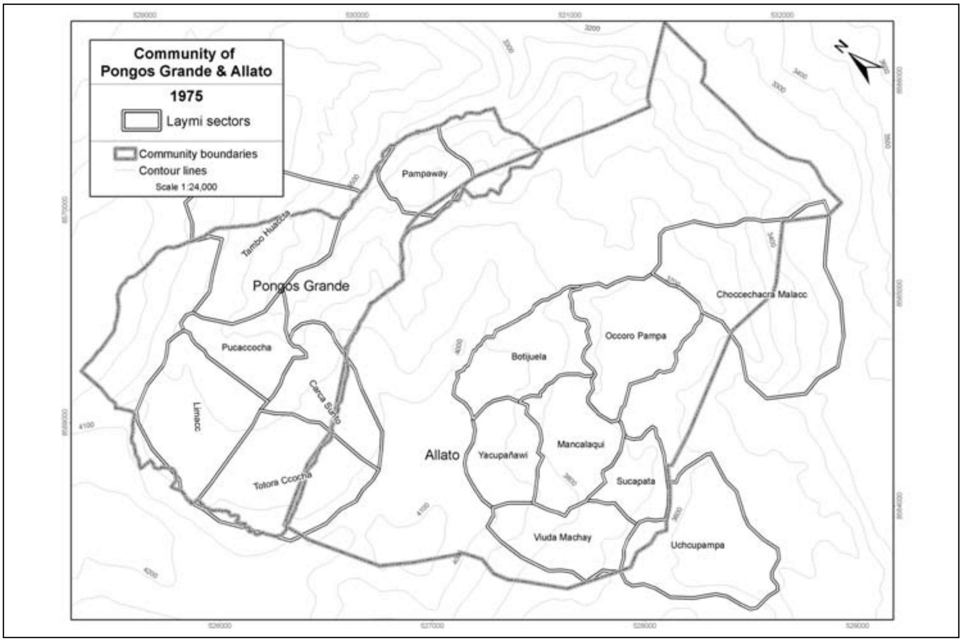
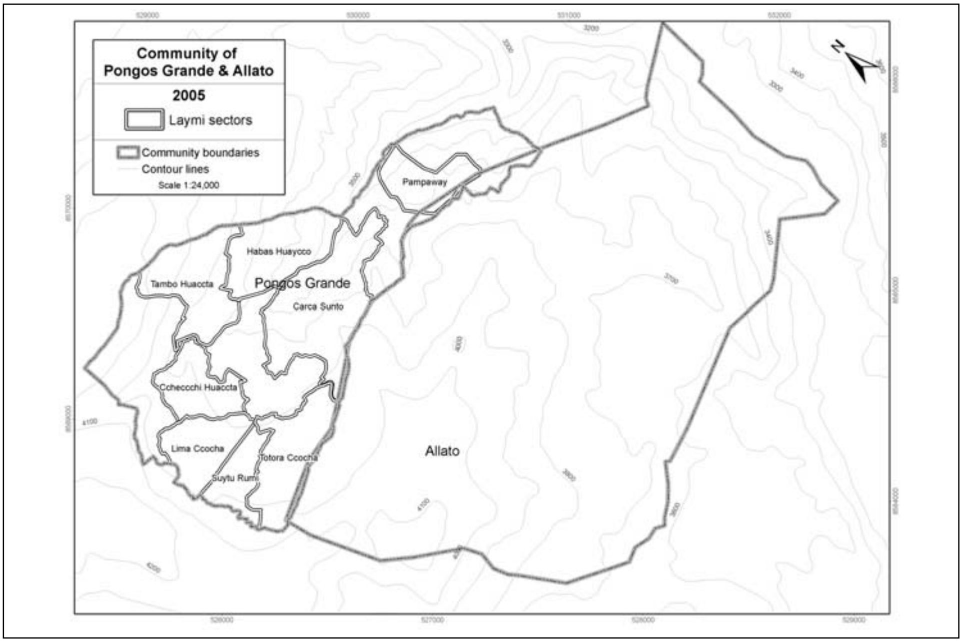


Figure 5.5: *Laymi* sectors of the neighboring communities of Pongos Grande and Allato - 2005



A second innovation allows family-assigned fields within each *laymi* sector to be excluded from communal decision-making and rotation design if these are fenced. This innovation has been inspired by the former hacienda system of family usufruct for assigned fenced plots (box 5.2). Families are increasingly withdrawing fields from the *laymi* system by fencing their fields, especially in the fertile low altitude sector of *Carca Sunto*. This allows for the intensification of family cropping schemes and reduced fallow periods. A negative side effect has been the gradual reduction of fallow pastures, resulting in overgrazing.

A third innovation involves the adaptation of sectoral rotation designs to local knowledge about soil fertility and relative distance from the community's nucleus. Such is the case for the *laymi* sector of *Pampaway* which is a low-altitude and distant sector characterized by low soil fertility and a consequent need for longer fallowing periods. The sector is currently excluded from the sectoral rotation sequence and only assigned for cultivation when considered sufficiently fertile. The sector was assigned for cultivation in 2006 after a fifteen-year fallow period.

Table 5.8: Sectors, crops and fallow periods of Pongos Grande's current sectoral fallow system

Sequence	Sector	Rotation design		
		Year 1	Year 2	Fallow period
1	*Carca Sunto*	hybrid and native potato	barley / olluco / fababeans / peas	5 years
2	*Totora Ccocha*	native potato	barley	5 years
3	*Suytu Rumi*	native potato	barley	5 years
4	*Lima Ccocha*	native potato	barley	5 years
5	*Checchi Huaccta*	native potato	barley	5 year
6	*Tambo Huaccta*	native potato	barley / oats	5 years
7	*Habas Huaycco*	hybrid and native potato	barley / fababeans	5 years
-	*Pampaway*	hybrid and native potato	barley / olluco / fababeans / peas	flexible

Source: participatory mapping, interviews and focus groups 2004-2005

5.4 Discussion and conclusions

Contemporary potato land use in the department of Huancavelica, central Peru, is highly dynamic and diverse changes were identified concerning land use tendencies, rotation designs and their intensity, and the fate of sectoral fallow systems. It is clear that these changes affect the medium- to long-term spatial arrangements of potato infraspecific diversity. However, it is harder to establish whether or not these changes will eventually be negative or positive for long-term sustainable conservation. Effects will most likely be indirect rather than result in a straightforward "wipe-out" of genetic diversity. Continued land use change in the Andes is a historical phenomenon; yet, farmers have often been able to establish new adaptive management regimes that are able to reestablish a new equilibrium between changing socio-economic environments and the maintenance of cultivar diversity. It remains important to learn from land use change and reflect upon the possible consequences for *in-situ* conservation.

Land use tendencies of the potato crop are characterized by a fast growing area of improved cultivars and a more or less stable area dedicated to native-floury and native-bitter cultivars. The increase of the area of improved cultivars is the likely result of multiple factors, including the ready availability of seed through markets or donations, comparative advantages such as earliness and partial resistance to late blight, constant market demand, their usefulness for traditional processes such as freeze-drying (case of the *Yungay* cultivar), among others. Areas of improved cultivars are proportionally growing fastest at high altitudes between 3,900 and 4,350 meters above sea level. Areas of genetically diverse native cultivars mixtures (*chaqru*) have remained relatively contact between 1995 and 2005. Indeed, there is no evidence to suggest a straightforward replacement of one cultivar category by another. Rather, reduced fallow periods for existing fields and the gradual incorporating of high-altitude virgin pasture lands sustain areal growth. The proportionally rapid areal expansion at high-altitudes is a consequence of human population growth. The cultivation of these new areas, especially those located above 4,000 m of altitude, imply high levels of production risk from frost, drought and hail.

Predominant potato-grain based rotation designs in Huancavelica still allow for significant periods of fallow even though the overall annual proportion of land under fallow is steadily decreasing. Human population growth and consequent increased demand for land to be cultivated is an important driver of this trend. Fields containing improved cultivars are more intensively cropped compared to fields containing native-floury or native-bitter cultivars. Results of this research also show that fallowing rates increase by altitude, reaffirming Godoy's (1984) observation that agricultural intensification is inversely related to altitude. The intensification of rotations resulting in reduced fallow periods of land already under cultivation is one of few options highland communities have to expand the annual area under cultivation. This does not necessarily affect potato genetic diversity positively or negatively. However, there is a limit to the intensity of crop rotations and carrying capacity of the land. If this limit is passed biotic and abiotic stress may eventually affect the *in-situ* conservation of diverse potato genetic resources. Indeed, it is well known that reduced fallows may imply a gradual reduction of overall soil fertility and increased pest or disease incidence.

Inquiry into the fate of well-know "hot-spots" of potato genetic diversity or sectoral fallow systems provides mixed lessons. With the exception of a single *laymi* circuit being maintained in the community of Pongos Grande, sectoral fallow systems have gradually disintegrated and been abandoned. As a consequence the spatial distribution of potato genetic diversity within the agricultural landscape has become patchier with cultivar diversity increasingly being unevenly distributed across the community territory rather than concentrated within a single *laymi* sector. This in itself does not necessarily imply a risk for potato genetic diversity. Again, long term sustainable conservation is put under increased pressure through indirect effects, likely including the higher incidence of pests and depletion of soil fertility. It has been suggested that communal property regimes impede private investment in agricultural land (Cotlear, 1989). However, results of this research show that innovations within sectoral fallow systems do potentially allow for increased household investment and intensified management.

6. Farmer seed systems and infraspecific diversity of potato in Peru's central Highlands

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Key words: seed storage, seed health, seed procurement, markets, biodiversity seed fairs, seed stress, genetic diversity, Huancavelica

Abstract

This paper investigates the relation between selected farmer seed system components (storage, health and procurement) and infraspecific diversity of potato in the department of Huancavelica, Peru. Procurement behavior of farmers and the role of farmer-to-farmer exchange, markets and seed fairs after normal and frost stressed years are compared. The study applied a range of research methods, including surveys and sampling exercises. Diverse potato cultivars, belonging to one of three cultivar categories, are managed unevenly within the overall seed system. Potato seed stores contain different seed lots, reflecting the rationales underlying management of cultivar diversity at the field level and the overall structure of infraspecific diversity. The potato viruses PMTV, PLRV and PVY are of limited importance while APMoV and PVX pose a threat to seed health.

During normal years seed acquisitions of native cultivars are characterized by transactions involving small quantities, few cultivars, few events of exchange, and seed flows over short distances. Most households exclusively use home produced seed of native cultivars. Communities where research was conducted are net seed exporters of native cultivars rather than importers. Uncommon native cultivars are exchanged infrequently and only few farmers provide them. The capacity of the farmer seed system to annually widely supply and distribute infraspecific diversity is limited. Yet, the farmer seed system is efficient at maintaining overall infraspecific diversity. Regular markets have a decentralized capacity to supply and widely distribute seed of selected cultivars. Frequencies of seed exchange at biodiversity seed fairs are low and involve small quantities of a few uncommon cultivars. The resilience of the farmer seed system to cope with severe regional seed stress (scarcity) is insufficient to be able to restore volumes and cultivar portfolios within a short period of time.

6.1 Introduction

6.1.1 Farmer seed systems and infraspecific diversity

Seed systems are an interrelated combination of components involving diverse actors (farmers and organizations), production systems (planting materials, management options and storage), processes (distribution and access) and institutions (regulatory frameworks and informal rules). Farmer seed systems, also commonly referred to as informal, local or traditional seed systems, are particularly important for smallholder and poor farmers (Louwaars, 2007). In the Andean countries over 95% of the potatoes grown originate from farmer seed systems (Ezeta, 2001). In Peru it is legally impossible to produce formal seed of the majority of native cultivars as these are not registered, and therefore not recognized, under the national seed law (MINAG and SENASA, 2004). Potato cultivar diversity is almost exclusively maintained through seed systems outside the formal regulation.

Farmer seed systems are potentially characterized by high levels of infraspecific diversity (Almekinders and Louwaars, 1999), mechanisms of provision embedded in social networks (Badstue, 2006; Badstue *et al.*, 2002; Tripp, 2001), resilience to withstand extreme events (Sperling, 2001; Sperling *et al.*, 2008), effectiveness at selection and diffusion of new cultivars (Aw-Hassan *et al.*, 2008; Jones *et al.*, 2001), wide distribution patterns (Thiele, 1999), and acceptable seed quality (Bertschinger, 1992). However, dynamic farmer seed systems typically also have shortcomings and not all farmers follow best local practices (Thiele, 1999).

Understanding the nature and operations of seed systems is central to the maintenance of diversity on-farm (Hodgkin and Jarvis, 2004). Farmer seed systems can be conceived as an overlay of infraspecific diversity determining its temporal and spatial patterning (De Haan and Thiele, 2004). In chapter 2 it was shown that farmers in Huancavelica maintain high levels of genetic diversity within the six cultivated potato species that are commonly grown in the region. Infraspecific diversity, or genetic diversity within the botanical species, is represented by an array of distinct cultivars. Individual households in Huancavelica maintain up to 160 unique potato cultivars.

This chapter reports the functioning of the farmer seed system in relation to infraspecific diversity in the potato's center of origin. Can the seed system be considered a uniform system or can different subsystems be distinguished for the three potato cultivar categories? An understanding of these differences is particularly relevant for *in-situ* conservation of infraspecific diversity. This study looks at storage management of diverse potato cultivars, virus infection within biodiverse seed stocks and seed procurement as components that characterize possible subsystems. In addition, the study analyzed the impact of climate fluctuations in the form of out-of-season frosts on cultivar loss and seed procurement after seed stress (scarcity).

6.1.2 Storage of infraspecific diversity

While several studies looked at in-field diversity management of potato diversity, little is known about seed storage management in relation to the diverse potato cultivar stocks maintained by farmers. Seed tubers are normally kept in one or two seemingly uniform storage facilities (Egúsquiza, 2000). But it is not known how seed stores are internally organized and how this relates to the overall cultivar diversity farmers plant. Differential management and end-uses of specific cultivars or mixtures partially drive the field separation of cultivars (chapter 4). How are diversity-rich farmer seed stores organized? Does the separate storage of potato cultivars reflect rationales behind the differentiated management of diversity at the field level or vice versa?

6.1.3 Seed health

Next to storage management, seed health was studied. It is one of the aspects of Andean potato seed systems that are debated (see Thiele, 1999). Some consider it as being remarkably well performing; others claim the contrary. In reality this aspect is little studied and hardly any data is available to support any general statement on the seed health in Andean potato seed systems. Potato seed health refers to the phytosanitary status of seed tubers, and includes the presence of viruses, fungi and bacteria. Viruses are generally seed-transmitted, therefore potentially affecting potato seed quality within farmer seed systems. Viruses are commonly considered to pose a particularly serious threat to seed health because of their potential detrimental impact on yield, wide distribution patterns and "hidden" nature (Salazar, 1997). APMoV (Andean Potato Mottle Virus), Potato Leafroll Virus (PLRV), Potato Mop-Top Virus (PMTV), Potato Virus Y (PVY) and Potato Virus X (PVX) are among the most important virus diseases affecting potato in Peru (CIP, 1996; Loebenstein *et al.*, 2001). APMoV is transmitted by *Diabrotica* leaf beetles, PLRV and PVY by aphids, PMTV by *Spongospora subterranea* and PVX mechanically (Bonierbale *et al.*, 2007; CIP, 1996; Franc and Banttari, 2001; Robert and Bourdin, 2001).

Bertschinger *et al.* (1990) encountered overall high virus infection rates in farmers' seed in the Peruvian central and southern highlands. Yet, at altitudes above 3,500 m degeneration rates are reportedly slow allowing farmers to maintain their own seed with little loss of quality and need to frequently renew seed stocks (Scheidegger *et al.*, 1989). Andean farmers in some regions are known to recognize and manage the effects of virus infection, for example by planting degenerated seed at high altitudes for "refreshment" or by seeking new disease-free seed from potato specialists in nearby uplands (Bertschinger, 1992; Zimmerer, 1991c). So, are viruses likely to limit potato seed health of native cultivars in Huancavelica? And if so, which viruses are most prominently present?

6.1.4 Seed exchange

Seed exchange may be needed when home saved stocks do not balance a household's demand for seed in term of quantity, quality or cultivar content. In chapter 4 it was shown that, depending on the specific community, households in Huancavelica grow a yearly total potato area of 0.3 to 1.1 hectares. Considering that a minimum of 2,500 kg of seed is used to plant 1 hectare, farmers need an approximate total amount of 750 to 2,750 kg of seed. Most of this demand is for planting diverse native-floury cultivars (53.7%) followed by improved (28.4%) and native bitter cultivars (17.9%).

Farmer seed exchange generally pursues the renewal or replacement of potato seed stocks. Renewal is based on the perceived health and physiological benefits of using other seed stocks than the own. It can either be the acquisition of seed of cultivars already in stock or the incorporation of new cultivars. The response to cultivar or seed loss is defined as replacement. Loss of seed of particular cultivars and its replacement through exchange is a recurrent event (Zeven, 1999).

Potato seed flows are spatially determined routes of exchange (acquisition or provision) characterized by distance, volume, cultivar content, mechanism of exchange, source and destination. Seed flows generally cover limited distances (Thiele, 1999), but can cross international frontiers (Velásquez, 2002). Seed exchange can be farmer-to-farmer or arranged through organizations such as regular markets, biodiversity seed fairs, private or governmental agencies (NGO's, extension programs, companies). Exchange is often arranged through social networks (Richards, 2007). Such social fabrics can be based on prestige and recognition, patron-client links or functional reciprocity. While monetary exchange always involves sales, non-monetary exchange may include barter (*trueque*), payment in kind (*minka*) or presents (Ferraro, 2004; Mayer, 2002). Few detailed case studies on potato seed exchange in the Andes have differentiated between cultivar categories or specific cultivars. Is farmer seed exchange effective at providing infraspecfic diversity? Where and how do farmers exchange potato seed? Does this vary for each of the different cultivar categories? And how does this vary between normal years and years after crop failure?

Regular daily and weekly rural markets in the Andes are a key meeting point for farmers where seed, food, animals, tools and other products are exchanged. Regular markets have a long history throughout the Andes (Larson *et al.*, 1995); yet, little is known about their role in seed provision. Biodiversity seed fairs are a relatively recent phenomenon. Since the first biodiversity seed fairs were organized in the late 1980´s the number of fairs organized by municipalities, governmental agencies and NGO´s has increased throughout Peru (Scurrah *et al.*, 1999). Currently, well over fifty biodiversity seed fairs are annually organized throughout the department of Huancavelica alone. They are typically organized around various crops and competition is central in the events: those participants who bring the largest number of cultivars are given a prize. These seed fairs are supposed to enhance the exchange of diverse cultivars among participants and visitors (Tapia, 2000; Tapia and Rosas, 1993). Yet, it is not known whether biodiversity seed fairs accomplish what they were originally designed for. What are the roles of markets and seed fairs in terms of seed offered (diversity, quantities)? Do these roles vary for the different cultivar categories?

6.1.5 Seed stress and resilience

Seed stress (scarcity) can be defined as the lack of sufficient quantities of seed of the desired quality or cultivars. Seed stress can be localized or regional, acute or chronic and caused by biotic or abiotic factors. Potato seed stress in the Andes is generally localized, acute and caused by extreme weather events such as hail, frost or drought. On rare occasions acute seed stress may be a regional problem. Resilience refers to the farmer seed systems ability to overcome seed stress, ultimately leading to a new equilibrium of desired seed stocks. Potentially, farmer responses to seed stress are diverse. Conventional channels of seed provision may be approached, including other farmers, regular markets or biodiversity seed fairs. However, when seed stress is regional and severe, seed system interventions such as donations organized through government or development agencies may become increasingly important.

Remington *et al.* (2002) propose a framework for analyzing seed security with a farmer household's relative vulnerability being a result of seed availability, access, and utilization. Availability relates to the supply of seed at a particular location and time. Access refers to a farmer's socially-determined ability to obtain planting material through exchange. Utilization depends on seed health, physiological quality and genetic adaptability of a particular seed lot. Emergency interventions often assume that seed availability is the main problem after a severe shock, discounting the possibility that local channels can supply good quality seed (McGuire, 2007). Is the farmer seed system able to respond to severe shocks resulting in seed stress? What are the roles of farmer-to-farmer exchange, regular markets and biodiversity seed fairs in a context of seed stress? What are the characteristics of external interventions providing seed aid? How are seed availability, access and utilization affecting seed recovery?

6.2 Materials and methods

6.2.1 Sampling of seed lots

A variety of data collection methods was used in different selected localities (fig. 6.1). During 2004 and 2005 a sampling exercise was carried out in farmer seed stores in eight communities. These communities are positioned along a north-south transect through the department of Huancavelica (see chapter 1). The exercise was aimed at gaining insight into the internal organization of seed stores and how this relates to the maintenance of infraspecific diversity. A seed lot is a physically separated pile of seed potatoes within a seed store. All seed lots belonging to a total of 157 households (n=157) were sampled; this represented approximately 32% of the population of the communities. Households were visited at random and a total of 772 seed lots were sampled. From each sample a total of 100 to 200 tubers were taken for identification of the general cultivar category (improved, native-floury or native-bitter) and specific cultivar composition of the sample (based on the number of tubers).

6.2.2 Incidence of potato viruses

Seed health, with particular emphasis on virus infection rates, was investigated by taking seed tuber samples from farmer's storage facilities. This was done in June 2005, a few weeks after the main harvest. A total of 22 households from the 8 communities provided seed tubers. A single seed tuber was taken randomly for each of the native cultivars farmer families had in stock. Improved cultivars were not included in this study. Households provided a minimum of 17 and a maximum of 158 cultivars (average of 60 cultivars / household; total of 1317 cultivars). ELISA tests (Enzyme-Linked Immunosorbent Assay) were conducted for the following viruses: APMoV (n=1317), PLRV (n=1317), PMTV (n=1317), PVY (n=1317) and PVX (n=610).

6.2.3 Survey of household seed exchange

A survey inquiring about 2003 and 2004 seed exchange (acquisition and provision) of native potato cultivars was conducted in 8 communities (n=125 households; approximately 25% of the total population). Improved cultivars were also not included in this particular survey. Acquisition refers to the purchase of seed while provision refers to the supply of seed. Each transaction was registered and detailed: cultivar composition, distance, volume, mechanism of exchange, source or destination. The 2002-2003 and 2003-2004 seasons were considered as "normal" production seasons by farmers: no severe regional events caused by drought, hail or frost had affected the potato crop.

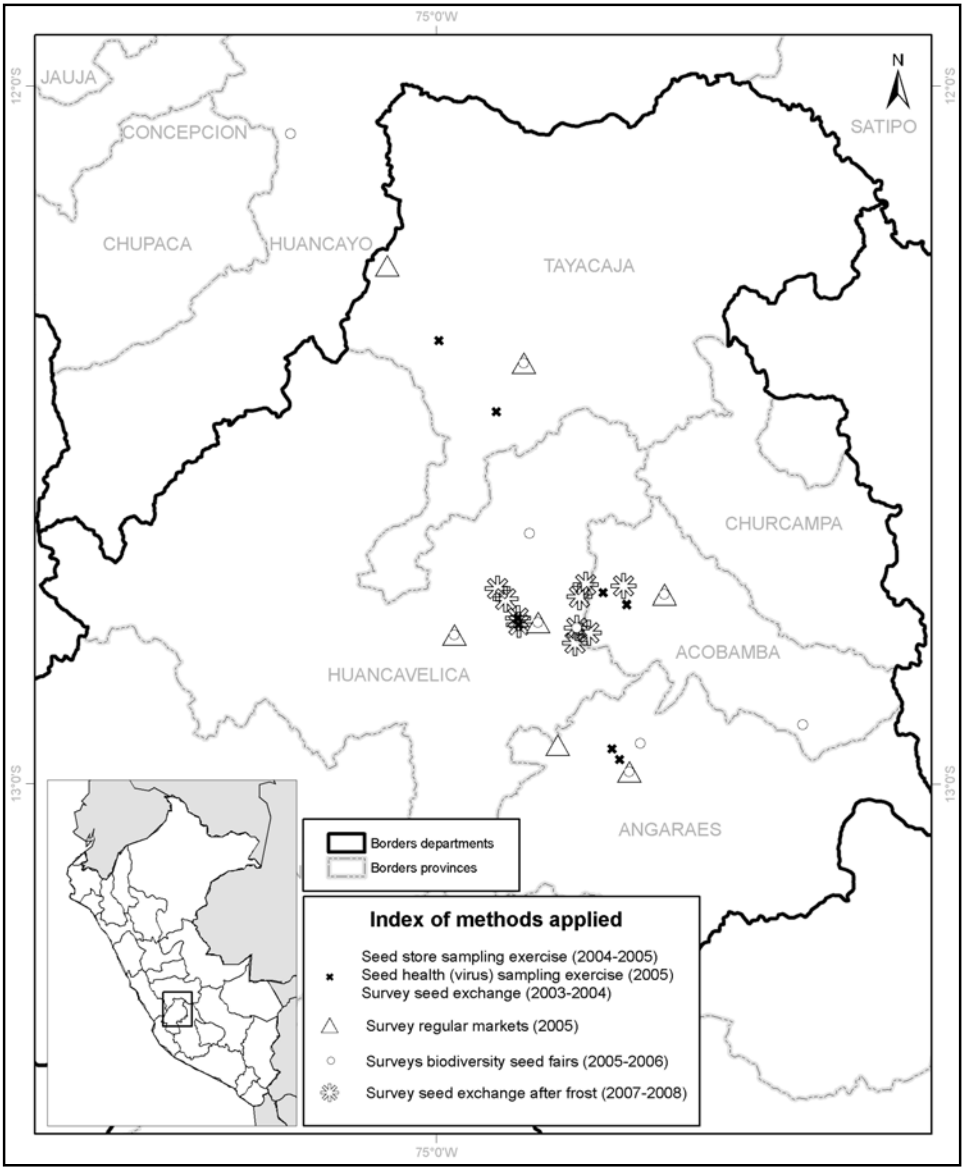
6.2.4 Surveys of seed exchange at markets and fairs

In 2005, 9 regular markets in the department of Huancavelica were visited and 73 vendors surveyed (n=73; see appendix V). These markets were weekly and daily markets, normally under auspicion of the municipality authorities. The markets were selected on the basis of their regional recognized role as drivers of agricultural commerce. Individual transactions (n=183) involving seed provision during the 2005 dry season were detailed with vendors specifying cultivars and quantities sold. Additionally, between 2005 and 2006, 10 biodiversity seed fairs were visited and 76 participating farmers surveyed (n=76; see appendix VI). The surveys inquired about all cultivar categories (improved, native-floury, native-bitter) and specific seed exchange transactions were detailed.

6.2.5 Survey of seed procurement after a severe frost

On February the 17th 2007 a severe frost affected potato cropping areas in central Peru (Los, 2007). It was an extreme and unusual event and as a consequence acute regional food and seed shortages were imminent. The central government declared Huancavelica, among other departments, an emergency zone. This created a special situation in which regional governmental offices received the mandate and resources to provide seed and food to the affected communities. This shock to the seed system presented itself as a natural experiment to understand resilience. A large survey was conducted at the start of the 2007 - 2008 cropping season to characterize potato seed procurement after the extreme event. The survey involved households (n=280) from 10 communities from central Huancavelica: Villa Hermosa, Pucara, Chuñunapampa, Sotopampa, Ccasapata, Santa Rosa, Ccolpaccasa, Huachua, Chopccapampa and Limapampa (fig. 6.1).

Figure 6.1: Map of the localities where specific methods were applied



6.3 Results

6.3.1 Storage of infraspecific diversity

Potato seed stores in Huancavelica are physically separated buildings or rooms which either contain "*trojes*[1]" or bags with seed. Households in Huancavelica manage an average of 4.9 different potato seed lots per household within their stores. Yet, considerable differences exist between households within and between communities for the total number of seed lots as well as for the number of seed lots of the different cultivars categories (table 6.1). While households in the community of Tupac Amaru managed an average of 3.5 seed lots their counterparts in Dos de Mayo managed 7.9 seed lots per household. Farmers from Dos de Mayo managed more seed lots of native-floury and native-bitter cultivars compared to the other communities while farmers from Pongos Grande managed more seed lots of improved cultivars. The majority of the households had seed lots of native-floury cultivars (93.0%), whereas 61.8 % and 35.0% of the households had seed lots of respectively improved and native-bitter cultivars. Further, more seed lots with native-floury cultivars (average 3.4) were stored by individual households compared to improved (average 1.9) and native-bitter cultivars (average 1.7). This clearly reflects the relative importance of the different cultivar categories. Few households managed up to a maximum of 15 separate seed lots in their stores. The maximum number of seed lots per household was generally higher for native-floury cultivars compared to the other categories.

In total 97 households managed 183 individual seed lots of improved cultivars containing 11 different cultivars. Without exception each individual lot contained one single cultivar (no mixtures were found). The improved cultivars *Yungay* and *Canchan* were the most abundant and represented 51.2% and 23.2% of the seed lots of improved cultivars. The improved cultivars *Mantaro* and *Renacimiento* were the least abundant and accounted for only 0.6% and 1.2% of seed lots. Other improved cultivars in the samples were *Perricholi*, *Amarilis*, *Mariva*, *Capiro*, *Liberteña*, *Revolución* and *Unica*.

Seed lots containing native-floury cultivars were most numerous; 496 individual seed lots belonging to 146 different households were sampled. Complete cultivar mixtures (*chaqru*) were encountered in 164 seed lots, representing 33.1% of the total number of native-floury cultivar seed lots sampled. A total of 97 different native-floury cultivars were encountered in 332 seed lots containing one single cultivar (66.9% of total sample size); 51 of these cultivars were only encountered once as single-cultivar seed lots. The native-floury cultivars *Peruanita* and *Ajo Suytu* were the most abundant and encountered respectively in 15.1% and 9.6% of the seed lots containing one single native-floury cultivar (n=332).

Only 55 households had seed lots of native-bitter cultivars in their stores. A total of 95 seed lots were found: 19 contained complete cultivar mixtures (*chaqru*) (20.0%) and 76 were single cultivar seed lots (80.0%). Four cultivars (*Qillu Manwa*, *Puka Qanchillu*, *Yuraq Qanchillu*, *Yuraq Waña*) were only encountered once as single-cultivar seed lots. The native-bitter cultivars *Yana Manwa* and *Yuraq Siri* were the most abundant and found in 43.4% and 36.8% of single cultivar seed lots of this category.

[1] Elevated wooden or adobe seed store bed containing seed tubers covered by straw (*Stipa ichu*).

Table 6.1: Number of seed lots kept in storage by individual households between harvest and planting

Communities	Potato (general)						Improved cultivars						Native-floury cultivars						Native-bitter cultivars					
	Sample size		Av.	SD (±)	Min.	Max.	Sample size		Av.	SD (±)	Min.	Max.	Sample size		Av.	SD (±)	Min.	Max.	Sample size		Av.	SD (±)	Min.	Max.
	N[1]	N[2]					N[1]	N[2]					N[1]	N[2]					N[1]	N[2]				
Huayta Corral	21	79	3.8	2.3	1	10	0	0	-	-	-	-	21	59	2.8	2.1	1	8	16	20	1.3	0.4	1	2
Tupac Amaru	17	59	3.5	1.5	1	7	5	6	1.2	0.4	1	2	17	49	2.9	1.4	1	6	4	4	1.0	0.0	1	1
Vi. Hermosa	20	81	3.9	2.6	1	9	14	22	1.4	0.8	1	3	14	40	2.9	1.9	1	7	8	19	2.1	0.8	1	3
Pucara	21	93	4.5	2.5	1	12	19	32	1.7	0.7	1	3	18	41	2.3	2.0	1	9	11	20	1.8	0.6	1	3
Dos de Mayo	18	142	7.9	4.3	2	15	12	19	1.6	0.7	1	3	18	104	5.8	3.2	1	12	7	19	2.7	1.4	1	5
Libertadores	19	124	6.5	3.8	1	13	10	21	2.1	1.6	1	6	18	92	5.1	3.0	1	11	9	11	1.2	0.7	1	3
Pon. Grande	20	102	5.1	2.0	2	10	18	44	2.4	1.6	1	7	20	58	2.9	1.3	1	6	0	0	-	-	-	-
Allato	21	92	4.4	2.2	2	10	19	39	2.1	0.8	1	3	20	53	2.7	2.0	1	7	0	0	-	-	-	-
Total	157	772	4.9	3.1	1	15	97	183	1.9	1.1	1	7	146	496	3.4	2.5	1	12	55	93	1.7	0.9	1	5

[1] = households; [2] = seed lots

6.3.2 Seed health

The incidence of Andean Potato Mottle Virus (APMoV) in seed lots of native potato cultivars was moderately high with an overall average infection rate of 18.1%. Average infection rates in family seed stocks ranged from a minimum of 7.0% to a maximum of 30.0% (table 6.2). Notable differences between the 8 communities exist with average infection rates ranging from 9.5% (Huayta Corral) to 25.0% (Allato).

Table 6.2: Average rates of virus infection in seed stocks of selected farmer families

Farmer family	APMoV		PMTV		PLRV		PVY		PVX	
	N[1]	%	N[1]	%	N[1]	%	N[1]	%	N[1]	%
Fam. Quispe Flores	22	13.6	22	0	22	4.5	22	0	5	40.0
Fam. Curipaco Villalba	71	7.0	71	0	71	2.8	71	2.8	30	53.3
Fam. Cano Castillares	23	13.0	23	4.3	23	0	23	0	7	28.6
Fam. Huatarongo Mucha	36	13.9	36	0	36	0	36	0	9	77.8
Fam. Huamán Rojas	25	12.0	25	0	25	0	25	4.0	2	50.0
Fam. Ramos Pari	83	15.7	83	4.8	83	2.4	83	0	41	43.9
Fam. Ramos Cóndor	158	10.1	158	5.1	158	0.6	158	0	74	35.1
Fam. Ramos Matamoros	17	11.8	17	0	17	0	17	0	10	50.0
Fam. Huamán Matamoros	92	28.3	92	4.3	92	0	92	0	22	45.5
Fam. Paytan Mayhua	89	22.5	89	14.6	89	1.1	89	1.1	56	58.9
Fam. Paytan Ccantu	78	16.7	78	1.3	78	1.3	78	0	46	32.6
Fam. Quinto Matamoros	93	18.3	93	0	93	2.3	93	0	20	50.0
Fam. Palomino Carvajal	35	20.0	35	2.9	35	0	35	0	16	43.8
Fam. Cahuana Sedano	59	18.6	59	0	59	0	59	0	18	44.4
Fam. Raymundo Escobar	67	20.9	67	9.0	67	0	67	3.0	38	47.4
Fam. Raymundo Taipe	43	14.0	43	7.0	43	18.6	43	0	16	56.3
Fam. Escobar Raymundo	33	12.1	33	0	33	3.0	33	3.0	16	50.0
Fam. Montes Quispe	34	14.7	34	8.8	34	0	34	2.9	26	61.5
Fam. Velásquez Sánchez	103	25.2	103	6.8	103	1.0	103	1.0	55	50.9
Fam. Segama Velito	55	23.6	55	5.5	55	0	55	1.8	36	47.2
Fam. Janampa Rua	50	30.0	50	2.0	50	0	50	2.0	29	34.5
Fam. Janampa Martínez	51	21.6	51	5.9	51	0	51	0	38	55.3
Overall	1317	18.1	1317	4.4	1317	1.5	1317	0.8	610	47.0

[1] number of cultivars (equivalent to tubers as one tuber per cultivar was sampled randomly)

The overall average infection rate of Potato Mop-Top Virus (PMTV) was relatively low at 4.4%. Seed stocks of 8 out of 22 farmer families were completely free of PMTV. Yet, seed stocks of 14 out of 22 farmer families were infected with average infection rates in family seed stocks ranging from a minimum of 1.3% to a maximum of 14.6%. The community of Huayta Corral was found to be free of PMTV based on seed samples taken for each cultivar (n=116) from 3 of its conservationist farmer families. All other communities showed some presence of PMTV with average infection rates ranging from 0.5% (Dos de Mayo) to 8.2% (Libertadores).

As Potato Leafroll Virus (PLRV) is aphid transmitted one would expect minimal presence in Huancavelica where climate conditions are adverse for aphids due to altitude. Indeed, the overall average infection rate was only 1.5% and seed stocks of 12 out families were completely free of PLRV while seed stocks of 10 families were infected with average infection rates ranging from 0.6% to 18.6% per family. The communities of Tupac Amaru and Allato were found to be free of PLRV based on seed samples taken for each cultivar (n=217) from 5 of its conservationist farmer families. The other communities showed some presence of PLRV with average infection rates ranging from 0.8% (Pucara) to 7.3% (Libertadores).

Potato Virus Y (PVY) is also transmitted by aphids and perpetuated through infected tubers. The overall average infection rate was very low (0.8%) and seed stocks of 13 out of 22 farmer families were completely free of PVY. Seed stocks of the other families were infected with average infection rates ranging between 1.0% and 4.0% per family. The communities of Villa Hermosa and Dos de Mayo were found to be free of PVY based on seed samples taken for each cultivar (n=445) from 6 of its conservationist farmer families. The other communities showed some presence of PVY with infection rates ranging from 0.4% (Pucara) to 1.8% (Libertadores and Pongos Grande).

The incidence of the mechanically transmitted Potato Virus X (PVX) was severe with an overall average infection rate of 47.0%. Average infection rates in family seed stocks fluctuated between 28.6% (minimum) to 77.8% (maximum) while average infection rates at the community level ranged from 39.2% (Villa Hermosa) to 72.7% (Tupac Amaru).

6.3.3 Seed exchange

Exchange during normal years

Of the farmers (n=124) interviewed about exchange of seed of native cultivars (both native floury and native bitter), 41.1 % indicated to use home-produced seed of native potato cultivars as normal practice. Households acquiring seed from elsewhere do so to add seed to their home saved stocks. Complete renewal of seed stocks is uncommon, even of single cultivars. The frequencies of partial seed stock renewal vary among farmers: 18.5% of the farmers renew part of their seed stock yearly, 17.7% every two years, 8.9% every three years, and 12.6% every four to six years. The proportion of households having acquired and provided seed of native cultivars in 2003 and 2004 varied considerably between communities and years (table 6.3).

More households provided (42.4 - 52.8%) rather than acquired (21.0 - 29.6%) seed of native cultivars during both years of inquiry (table 6.3). For those households exchanging seed, the number of annual transactions involving provision was always higher compared to events involving acquisition. Most households acquiring seed did so only once a year (84.9%); only few households were involved in two (13.7%) or three (1.5%) annual transactions to acquire seed. While most households providing seed of native cultivars were only involved in a single annual transaction of provision (59.9%), a comparatively high proportion of households was involved in two (29.6%), three (8.8%) or four (1.8%) transactions. Farmers look for seed of new (60.3%) or lost (41.1%) native cultivars, rather than for common cultivars already in stock (19.1%) when they acquire seed. Yet, when it comes to provision, 67.6% of farmers provide common rather than uncommon cultivars.

Table 6.3: Percentages of households having acquired / provided seed of native cultivars (n=125)

Community	N	2003		2004	
		Acquired (%)	Provided (%)	Acquired (%)	Provided (%)
Huayta Corral	24	12.5	16.7	41.7	50.0
Tupac Amaru	16	31.3	25.0	12.5	43.8
Villa Hermosa	22	27.3	36.4	27.3	40.9
Pucara	9	22.2	66.7	22.2	66.7
Dos de Mayo	12	50.0	75.0	50.0	66.7
Libertadores	16	6.7	37.5	25.0	37.5
Pongos Grande	14	0.0	78.6	21.4	78.6
Allato	12	25.0	41.7	33.3	58.3
Overall	125	21.0	42.4	29.6	52.8

The quantities of seed acquired were relatively small with an average of 25.3 and 69.5 kg per household for 2003 and 2004 respectively (table 6.4). Depending on the community this represents a minimum of 0.8% and a maximum of 7.7% of the annual household need for seed. Between 86.2% (2003) to 96.2% (2004) of the acquisitions of native cultivars involved less than 100 kg. Quantities of seed provided were higher than those acquired, with an average of 372.7 and 489.0 kg per household for 2003 and 2004 respectively. Between 43.2% (2003) and 54.3% (2004) of the seed provisions of native cultivars involved more than 100 kg.

Table 6.4: Quantities of seed of native cultivars acquired and provided by households

Year	Flow	N	Distribution: volume exchanged (%)						Weight (kg)			
			< 5	5-25 kg	25-100 kg	100-500 kg	500-1000 kg	> 1000 kg	Av.	SD (±)	Min	Max
2003	Acquired	27	29.6	37.0	29.6	3.7	-	-	25.3	28.0	0.5	120
	Provided	51	2.0	17.6	37.3	27.5	11.8	3.9	372.7	977.2	3.0	6700
2004	Acquired	36	16.7	41.7	27.8	11.1	2.8	-	69.5	134.9	0.4	600
	Provided	59	1.7	10.2	33.9	39.0	11.9	3.4	489.0	1826.8	2.0	14000

The average number of native cultivars being exchanged by households as seed was relatively low (table 6.5). In 2003 surveyed households (n=125) acquired and provided a total of 25 and 28 different cultivars while in 2004 households acquired and provided 57 and 34 different cultivars respectively. During both years most cultivars showed low frequencies of exchange and were consequently only acquired or provided by a single household (table 6.6). These were generally non-commercial native-floury cultivars preferred for home consumption. Without exception those native cultivars with high frequencies of exchange were well-known cosmopolitan cultivars for renewal of commercial seed stocks.

Table 6.5: Average number of native cultivars exchanged per transaction

Year	Flow	N[1]	Av.	SD (±)	Min.	Max.[2]
2003	Acquired	27	3.7	3.7	1	10
	Provided	53	5.8	3.8	1	10
2004	Acquired	36	3.5	2.5	1	10
	Provided	66	5.4	3.7	1	10

[1] = number of registered transactions; [2] = based on average cultivar content of complete cultivar mixtures (*chaqru*)

Table 6.6: Total number of native cultivars exchanged by relative frequencies of exchange

Frequency	2003				2004			
	Acquired		Provided		Acquired		Provided	
	No.	%	No.	%	No.	%	No.	%
Low freq. of exchange (1)	17	68.0	12	42.9	39	68.4	17	50.0
Medium freq. of exchange (2-5)	7	28.0	9	32.1	13	22.8	9	26.5
High freq. of exchange (>5)	1	4.0	7	25.0	5	8.8	8	23.5
Total	25	100	28	100	57	100	34	100

Family members and farmers, as well as regular markets and yearly agricultural fairs, were reported to be important sources for seed exchange of native cultivars during both periods of inquiry (table 6.7). Farmers did not consider governmental and development organization important sources of supply or demand for seed during these normal years without severe regional events affecting potato production negatively.

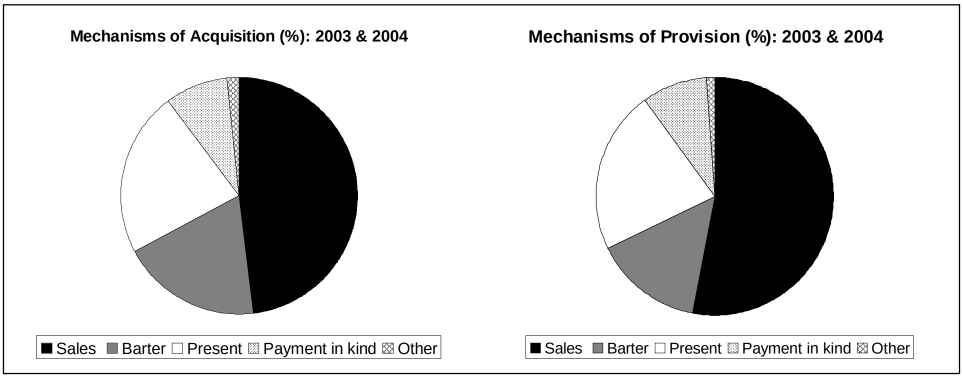
When acquiring seed through sales, barter or payment in kind (*minka*), most farmers evaluate seed quality, mainly by looking at visible health parameters (83.3%) and seed size (73.6%). When receiving seed as a present no claim can be made by the receiver, yet this is rarely necessary as gifts tend to be a the highest possible quality as providers aim to reaffirm social relationships. Seed is considered healthy looking when it has a regular shape and shows no skin irregularities.

Table 6.7: Commonly used sources for seed exchange of native potato cultivars (n=72)

	Acquisition (%)	Provision (%)
Family member from the same community	27.8	43.1
Farmers from the same community	18.2	27.8
Farmers from other communities	22.2	26.4
Regular markets / yearly fairs in other communities	44.4	43.1
Seed company	2.8	-
Others	2.8	1.4

Exchange through sales was the most frequently used mechanism of seed acquisition and provision, followed in importance by presents, barter and payment in kind (fig. 6.2). Other mechanisms such as loans to and from other farmers or donations from organizations were infrequent. Sales generally involved larger volumes of a limited number of cultivars while presents mostly related to small volumes containing diverse cultivars. Each of the mechanisms is embedded within a distinct social context. Sales are socially more neutral for those who can afford to pay in cash. Sales are transactions that are done with as soon as the merchandise is cancelled while presents aim to strengthen social ties and assure future payback when times are meager. Barter and payment in kind (*minka*) are more accessible mechanisms for those farmers without access to cash. Typically, barter can involve a range of different products, such as cloth, wool or seeds of another crop or cultivar, to be exchanged for potato seed. In Huancavelica, exchange through *minka* generally involves payment with the same produce workers are harvesting.

Figure 6.2: Most frequently used mechanisms of seed acquisition (n=90) and provision (n=89)



Most of the 2003 (85.7%) and 2004 (74.4%) seed acquisitions originated from within the provincial boundaries of the 7 provinces that constitute the department of Huancavelica. A similar pattern can be observed for seed provision with 84.6% and 88.8% of the 2003 and 2004 transactions ending up within the province where the seed had been produced (fig. 6.3). Relatively few seed exchanges pass geopolitical boundaries at the provincial and departmental level. On average only 11.8% of the transactions passed provincial limits, yet remained within the department of Huancavelica. Exchanges exceeding departmental boundaries only represented 6.5% of the total number of transactions. On average seed flows covered distances ranging between 15.2 and 49.4 km, depending on the process (acquisition or provision) and year (2003 or 2004). Yet, when looking at frequencies (%), most transactions covered less than 25 km (table 6.8). Only 5.5% of the total number of seed exchanges covered right-angle distances of more than 100 km.

Figure 6.3: Geopolitical nature of individual events of seed acquisition (n=71) and provision (n=176)

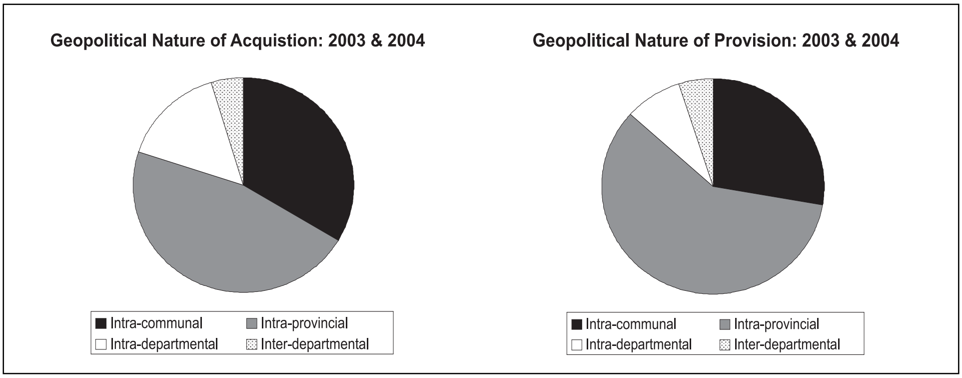


Table 6.8: Distances (right-angle) covered by individual seed flows

Year	Process	N	Distribution: distances seed exchanged (%)						Distance (km)			
			< 1 km	1-5 km	5-25 km	25-100 km	100-200 km	> 200 km	Av.	SD (±)	Min.	Max.
2003	Acquired	29	41.4	6.9	34.5	17.2	-	-	15.7	25.7	0.2	98
	Provided	79	26.6	7.6	50.6	11.4	2.5	1.3	18.0	36.4	0.2	258
2004	Acquired	44	29.5	6.8	43.2	4.5	9.1	6.8	49.3	112.5	0.2	528
	Provided	96	29.2	2.1	55.2	11.5	2.1	-	15.2	21.9	0.2	134

The role of regular markets

A range of vendors (n=73) at daily and weekly regular markets was interviewed (see appendix V for more detail), including wholesalers (38.4%) and retailers (61.6%). Wholesalers were typically able to provide at least a quarter of a ton of potatoes if demanded while retailers provided relatively small quantities. Overall, 68.8% of vendors were also potato producers. An average of 23.3% of vendors only sold potatoes they themselves produced, while 39.7% only traded potatoes they bought from other farmers and 37.0% provided both self-produced and purchased potatoes. An average of 61.1% of vendors sold potatoes produced in the department Huancavelica; about three-quarters of these potatoes originated in the province of Tayacaja. The proportion of produce from Junín was appreciable with an average of 38.9% of vendors providing potatoes originating in this department.

An average of 63.0% of the vendors sold both improved and native cultivars while only 34.2% and 2.7% sold exclusively improved or native cultivars respectively. The total infraspecfic diversity offered at regular markets was relatively low with an average of 4.6 and a maximum of 8 cultivars per vendor (table 6.9). Appendix VII provides a general overview of the 28 cultivars offered fore sale on regular markets. The average daily volumes offered per vendor fluctuated between 5 to 4,800 kg, depending on the cultivar and vendor. The most commonly available cultivars, both in terms of volume and number of vendors offering them, were: *Yungay*, *Canchan*, *Larga*, *Wayru*, *Amarilla Runtus*, *Andina*, *Perricoli*, *Camotillo* and *Peruanita*. An average of 11.1% of the vendors sold complete cultivar mixtures (*chaqru*). Depending on the cultivar, average prices fluctuated between 0.55 and 1.80 Peruvian Soles per kg (0.17 - 0.54 US dollars in the survey year). Few vendors (1.4%) offered fresh (non-processed) tubers of native-bitter cultivars.

Table 6.9: Number of different cultivars offered at the regular markets in Huancavelica

Market	N	Average per vendor (*)	SD (±)	Min.	Max.
Ccochaccasa Market	5	3.6	1.1	2	5
Huanc. Sunday Market	8	4.8	1.7	3	8
Paucara Sunday Market	12	4.7	1.0	3	6
Pampas Sunday Market	16	3.8	1.6	3	8
Lircay Sunday Market	9	5.0	1.4	3	8
Huanc. Saturday Market	3	5.0	1.0	4	6
Yauli Saturday Market	2	2.5	2.1	1	4
Pasos Saturday Market	3	3.0	1.0	2	4
Permanent Market Hcva.	15	5.7	1.6	3	8
Total	73	4.6	1.6	1	8

* complete mixtures of native-floury cultivars (*chaqru*) excluded from the calculation

Vendors recalled seed transaction on the basis of demand: transactions based on the client explicitly requesting seed instead of consumption potatoes. Depending on the market, 46.7% to 100% of the vendors sold potato seed in addition to trading consumption potatoes. Averaged over all markets, 63.0 % of the vendors sold seed. The Saturday market in Yauli was the only exception as none of the vendors sold seed. Those vendor who did sell seed during the 2005 dry season, did so providing seed to an average of 8.8 (± 6.4) farmers (min. 1 / max. 25) during the season. Most vendors (66.7%) typically provided less than 50 kg of seed per individual transaction while only few vendors provided between 50 to 100 kg (20.0%) and 100 to 500 kg (11.1%). Sales involving more than 500 kg of seed were uncommon (2.2%).

An average of 56.4% of the vendors exclusively sold tubers of consumption potatoes as seed without any kind of selection or formal guarantee (table 6.10). A small number of vendors (15.4%) exclusively offered selected tubers of what is commonly known as "*semilla común*". The informal category "*semilla común*" (common seed) refers to reselected seed tubers from stocks of consumption potato without any formal guarantee accrediting seed quality. Selection is predominantly based on tuber-size and external (visible) seed health. An average of 28.2% of vendors sold both consumption potatoes and selected tubers as seed. When asked about guarantees, 87.0% of the vendors told that transactions were based on trust while 19.6% indicated they had formally certified seed on offer (no accreditations were shown). Trust was interpreted very widely by vendors, either meaning that: a) the costumer should just trust him (little guarantee), b) the vendor was recommended by a third party (medium guarantee), c) the seller was known to the customer and had provided seed of good quality in the past (high guarantee).

A total of 389 individual seed transactions from 46 regular market vendors to farmers were registered; 183 were detailed by vendors (table 6.11). The transactions detailed involved more than 27 cultivars (8 improved; 19 native-floury including *chaqru* mixtures) and a total volume of 57,392 kg (36,617 kg improved; 20,775 kg native-floury). These transactions, to be used for the 2005-2006 agricultural season, served a total of 63 farmer communities covering all 7 provinces of the Huancavelica department. Extra-departmental seed flows from regular markets in Huancavelica were limited, representing only 2 out of 63 registered destinations and 4.0% of the total number of transactions. All vendors indicated that the yearly demand for seed fluctuates considerably with high levels of damage from frosts and hails causing increased demand.

Table 6.10: Kind of seed offered by vendors who offered seed potatoes for sale at regular markets (n=46)

Market	Exclusively tubers of consumption potatoes as seed without selection A / (%)	Exclusively tubers selected as seed: size and external health B / (%)	Both consumption potatoes and selected tubers A + B / (%)
Ccochaccasa Market	25.0	50.0	25.0
Huanc. Sunday Market	60.0	20.0	20.0
Paucara Sunday Market	66.7	16.7	16.7
Pampas Sunday Market	71.4	14.3	14.3
Lircay Sunday Market	42.9	14.3	42.9
Huanc. Saturday Market	50.0	0	50.0
Yauli Saturday Market	-	-	-
Pasos Saturday Market	33.3	0	66.7
Permanent Market Hcva	80.0	0	20.0
Overall	56.4	15.4	28.2

The details of seed transactions show that native-bitter cultivars were not traded as seed (no transaction were registered). The 8 cultivars offered by most vendors (> 10%) are well-known cosmopolitan improved (4) and native-floury (4) cultivars which are also commonly found in urban markets of Huancayo and Lima. The number of transactions involving seed sales of these cultivars and the quantities sold are considerably higher compared to the other cultivars. Out of the 15 cultivars offered by very few vendors (< 5%), 12 are little-known native-floury cultivars of regional importance. With the exception of the cultivar *Tumbay*, their use is typically restricted to home consumption or sales at local niche markets. The other 3 are improved cultivars which have gone out of demand as commercial ware potatoes (*Renacimiento*, *Revolución*) or have only been released recently (*Unica*). Only a single transaction was registered for 10 out of the 15 cultivars offered by few vendors. In all cases their traded volume was relatively low compared to cosmopolitan cultivars. The foregoing presents an imminent pattern of limited infraspecific diversity being offered at regular markets, with few samples and small quantities of little-known cultivars being traded infrequently by selected vendors. An interesting exception are the complete cultivar mixtures (*chaqru*). *Chaqru* seed was offered by 9.3% of the vendors, involving 10 transactions averaging 128 kg each.

Table 6.11: Details of individual seed transactions (n=183)

Cultivar	%[1]	Cultivar Category		No. specific transactions registered (n)	Amount Sold (Kg.)			
		IC[2]	NFC[3]		Av.	SD (±)	Min.	Max.
'Amarillis'	14.0	X		7	371	243	100	700
'Amarilla Runtus'	7.0		X	12	169	145	50	500
'Andina'	14.0	X		10	573	1207	80	4000
'Ajo Suytu'	2.3		X	3	163	118	90	300
'Camotillo'	18.6		X	6	198	172	40	500
'Canchan'	58.1	X		26	620	1569	50	8000
'Casa Blanca'	2.3		X	1	100	-	-	-
Chaqru (*)	9.3		X	10	128	71	30	200
'Chaulina'	2.3		X	1	50	-	-	-
'Chunya'	4.7		X	1	24	-	-	-
'Huanuqueña'	2.3		X	1	50	-	-	-
'Kuchipa Akan'	2.3		X	1	18	-	-	-
'Larga'	51.2		X	24	183	200	30	800
'Perricholi'	7.0	X		4	145	95	50	250
'Peruanita'	30.2		X	20	324	462	40	2000
'Puqya'	2.3		X	2	38	3	36	40
'Renacimiento'	2.3	X		1	40	-	-	-
'Revolución'	2.3	X		1	200	-	-	-
'Saco Largo'	2.3		X	1	200	-	-	-
'Traqin Waqachi'	4.7		X	4	110	60	80	200
'Tumbay'	2.3		X	2	250	212	100	400
'Unica'	2.3	X		1	900	-	-	-
'Villa'	7.0		X	2	95	7	90	100
'Wayru'	18.6		X	12	299	614	30	2200
'Wayta Chuko'	2.3		X	1	40	-	-	-
'Witqis'	2.3		X	2	16	20	2	30
'Yungay'	62.8	X		27	372	773	12	4000

[1] = percentage of vendors selling the particular cultivar; [2] = improved cultivars; [3] = native floury cultivars; * *Chaqru* = a mix of native-floury cultivars

The role of biodiversity seed fairs

Every year numerous quite festive biodiversity seed fairs are organized throughout Huancavelica and neighboring departments. These fairs are based on competition between farmers showing their family collections of diverse potato cultivars. The winners, i.e. those who have the highest numbers of cultivars, receive incentives such as tools, kitchen utensils, food items or fertilizers. The types of incentives provided to participants differ per fair and most fairs combine expositions of agrobiodiversity with competitions involving livestock, local dishes or handicrafts (see appendix VI for more detail). Generally a jury with external experts is invited to evaluate the farmer collections and propose the winners of the competition. Evaluation criteria typically include cultivar diversity (number of cultivars), farmer knowledge (nomenclature, use criteria) and presentation of the samples (size and external health of tuber samples). Of the interviewed farmers who participated in the 10 seed fairs that this study looked at, 21.9% participated for the first time, while 46.6% had participated for at least four or more years in the same fair. While 28.8% only participated in a single fair a year, many participated in two (32.9%), three (13.7%), four (16.4%) or more (8.2%) annual biodiversity seed fairs.

About three quarters of the farmers (72.6%) knew some of the other participants at the same fair and most of these (69.9%) returned on a yearly basis, indicating that participants are a select group of farmers who are well-known to each other. This impression is supported by the finding that most farmers (61.6%) considered that only a few new participants were observed at the fairs. Farmers knew about the fair because they received an invitation (82.2%), heard about it on the radio (31.5%), were notified by other farmers (12.3%) or neighbors (4.1%), or because they remembered the place and date from previous years (1.4%). Farmer's personal motivations to participate in seed fairs were diverse and included: demonstrate their cultivars (45.2%), obtain recognition for the home community (32.9%), win a prize (27.4%), obtain personal recognition (21.9%), comply with invitation (19.2%), obtain new cultivars (15.1%), obtain new knowledge (11.0%), and obtain recognition for the family (6.8%). Farmer perception about the visitor's interest included four possible motives: observation of agrobiodiversity (47.1%), purchase of goods for consumption including potatoes (27.9%), a day out with the family (23.5%) and/or acquisition of seed potatoes (10.3%).

Of the farmers interviewed, 68 participated with native potato cultivars only whereas 5 farmers exclusively participated with improved cultivars. Participants typically showed 5 to 10 tubers of each cultivar. Farmers participating with native cultivars (n=68) on average presented 123 cultivars per family collection (n=68). Few farmers presented less than 25 cultivars (4.4%). Other farmers presented 25 to 50 (29.4%), 50 to 100 (26.5%), or 100-200 distinct cultivars (25.0%). A select group of farmers (14.8%) presented family collections consisting of more than 200 cultivars. A total of 86.0% of the respondents indicated most of their cultivar variability was a family inheritance while only 14.0% had obtained most cultivars through exchange.

Participant perception indicates that seed exchange at the fairs is not common; 60.0% considered that none, 23.3% that few and only 15.7% that some farmers exchange seed at the events (table 6.12). Nevertheless, there are some notable differences between fairs and indeed some may provide more incentive for exchange than others. A total of 14.3% of respondents indicated that biodiversity seed fairs could potentially be important events for exchange, but that in practice this does not occur because of competition. An average of 76.6% of respondents considered that farmers participating in the fairs are generally "*celoso*" (jealous) with their seed, meaning that these farmers will not exchange in order to maintain a comparative advantage over other competitors and thereby increase their likelihood to win a prize. When asked about their willingness to exchange seed, 37.7% indicated they would not exchange seed of any cultivar, 23.2% would be willing to exchange any of their cultivars, and 39.1% would only exchange well-known cultivars.

Table 6.12: Farmers perception about the portion of exhibiting farmers sharing seed at the biodiversity seed fairs (n=70)

Biodiversity Seed Fair		N	Frequency of seed exchange (%)					
			All (100%)	Majority (=75%)	Most (50-75%)	Some (25-50%)	Few (<25%)	None (0%)
1	V Feria Agricola	2	-	-	-	-	-	100
2	National Potato Day	10	-	-	-	10.0	30.0	60.0
3	Expo Agro Lircay	6	-	-	-	-	33.3	66.7
4	Expo Agro Yauli	8	-	-	-	62.5	12.5	25.0
5	Feria Agropecuaria	5	-	-	-	-	-	100
6	Festi Agro HCVA	19	-	-	-	21.9	36.8	42.1
7	Concurso Semillas	8	-	-	-	12.5	12.5	75.0
8	Feria Huanaspámpa.	5	-	-	-	-	40.0	60.0
9	Expo Yauris 2006	3	-	-	-	-	-	100
10	Feria Agropecuaria	4	-	-	-	-	25.0	75.0
-	Overall	70	-	-	-	15.7	24.3	60.0

An average of 21.1% of participants had acquired seed while 27.8% had provided seed at the 10 fairs where surveys were conducted. Depending on the fair, the percentage farmers having acquired or provided seed fluctuated between 0 - 66.7% and 0 - 50.0% respectively. The details of these exchanges are presented in table 6.13. Not only do few farmers exchange seed, those who exchange generally do so with few cultivars and small volumes. Most look for new cultivars at the fairs. An average of 35.6% of participants indicated that the fairs had allowed them to increase cultivar diversity. The most common mechanism of exchange was through sales, followed by barter. A few farmers (4.2%) also mentioned they would try and steal some seeds if they could.

Table 6.13: Details of farmers who had exchanged seed at biodiversity seed fairs

Farmer	Fair	Acquisitions (n=15)			Provisions (n=20)		
		No. cvs	Vol.	Mech.	No. cvs	Vol.	Mech.
Guillermo Torre H.	V Feria Agricola	-	-	-	>10	10 kg	Sales
Domingo Quispe C.	National Potato Day	5	7 tub.	Sales	5	10 tub.	Sales
Simon Layme R.	National Potato Day	3	5 tub.	Sales	4	4 tub.	Sales
Anorato Quispe R.	National Potato Day	1	0.5 kg	Sales	-	-	-
Benita Montes E.	National Potato Day	-	-	-	3	24 kg	Sales
Magno Toscano H.	National Potato Day	-	-	-	>10	6 kg	Sales
Gloria Taipe	VIII Ex. Agro Lircay	-	-	-	>10	120 kg	Sales
Isaac Ramos C.	XII Expo Agro Yauli	4	10 tub.	Barter	4	10 tub.	Barter
Felix Capani M.	XII Expo Agro Yauli	5	18 tub.	Barter	-	-	-
Belisario Ramos C.	XII Expo Agro Yauli	2	4 tub.	Barter	-	-	-
Donato Enriquez H.	XII Expo Agro Yauli	-	-	-	2	36 kg	Sales
Sofia Condor A.	XII Expo Agro Yauli	-	-	-	6	17 tub.	Sales
Santiago Escobar P.	Festi Agro HCVA	3	11 tub.	Barter	2	4 tub.	Barter
Julian Coba M.	Festi Agro HCVA	1	2 tub.	Sales	-	-	-
Benigno Pariona V.	Festi Agro HCVA	2	5 tub.	Barter	2	7 tub.	Barter
German Mendoza H.	Festi Agro HCVA	6	18 tub.	Sales	-	-	-
Victor Torre Q.	Festi Agro HCVA	19	19 tub.	Sales	-	-	-
Felix Curasma H.	Festi Agro HCVA	2	6 tub.	Barter	2	6 tub.	Barter
Moner Hidalgo A.	Festi Agro HCVA	-	-	-	2	24 kg	Sales
Luis Calderon S.	Festi Agro HCVA	-	-	-	4	2 kg	Sales
Juliana Ramos H.	Festi Agro HCVA	-	-	-	10	120 kg	Sales
Victoria Sotacoro A.	Concurso Semillas	2	4 tub.	Sales	-	-	-
Luisa Ataypoma Q.	Concurso Semillas	2	4 tub.	Sales	-	-	-
Felix Capani M.	Concurso de Semillas	-	-	-	10	32 tub.	Barter
Freddy Huatarongo R.	Concurso de Semillas	-	-	-	9	30 kg	Sales
Juan Ramos C.	Feria Huanaspámpa	-	-	-	5	5 tub.	Sales
Elicio Salasar H.	Expo Yauris 2006	8	8 tub.	Sales	-	-	-
Juan Ramos C.	Expo Yauris 2006	-	-	-	10	10 tub.	Sales
Nemecio Romero C.	Feria Agropecuaria	-	-	-	10	10 kg	Sales

6.3.4 Impact of frost and responses to seed stress

The severe frost that affected the central Peruvian highlands on February the 17th 2007 caused significant crop damage in Huancavelica. In the surveyed communities the frost affected 92.6 to 95.8% of the potato fields. The levels of damage perceived by farmers' right after the frost were reflected very accurately in real yield reductions in at harvest time (see appendix VIII for more detail). Yet, there were notable differences in frost damage between communities; these were probably related to agroecological variables (slope, altitude). Flat fields were particularly hard hit as cold air tends to go downhill and settle where it reaches valley bottoms. The measured minimum temperature was -4ºC and the frost even affected cultivar categories that are normally considered to be resistant: mixed stands of native-floury (*chaqru*) and native-bitter cultivars. Regional levels of yield reduction ranged from a minimum of 70.4% (native-bitter cultivars) to a maximum of 77.2% (mixed stands of native-floury cultivars) showing that general differences between the cultivar categories was minimal.

An average of 75.1% of farmers reported cultivar loss. Loss varied for the different cultivar categories, ranging from 15.4% for native-bitter cultivars to 69.3% for native-floury cultivars (details are presented in appendix IX), indicating that cultivar loss was proportionally more severe for the diverse cultivar category of native-floury cultivars. On average farmers lost 4.7 cultivars. The average number of cultivars lost was higher for the category of native-floury cultivars (4.3 cultivars lost) compared to improved and native-bitter cultivars (1.3 and 1.2 cultivars lost respectively). Farmers prioritized 5 main reasons for cultivar loss (n=241): cultivars were installed on flat terrain (71.8%), cultivars were susceptible to frost (55.2%), cultivars were already scarce and not abundant in fields (11.2%), cultivars were installed at exceptionally high altitude (10.0%), and the frost was exceptionally severe (6.2%).

An average of 23.3% of farmers lost all potato seed (table 6.14). However, levels of total seed loss differed considerably by community. While a majority of the farmers (69.2%) from the community Pucara lost all their seed none of the farmers in from Huachua suffered the same fate. For those farmers who were able to save seed, the volumes stored were low compared to normal years. Overall, farmers only saved about a quarter (25.2%) of the amount of seed they would store during a normal year, evidencing severe seed stress. A total of 97.8% of the farmers also indicated that the frost had affected seed quality: smaller seed size (71.2%), rotting (19.6%), tuber skin damage (11.1%), blackening (5.9%) and higher levels of damage from larvae of Andean weevil (5.5%; *Premnotrypes* spp.) were reported. The later is a consequence of farmers having limited choice and therefore having to include seed with recognized pest damage.

Table 6.14: Percentage (%) of farmers having lost all potato seed and volumes stored compared to a normal year

Community	N[1]	Farmers having lost all seed (%)	Percentage (%) of seed saved compared to a normal year				
			Potato	Improved cultivars	Native-floury cultivars (single cultivars)	Native-floury cultivars (mixed cultivars)	Native-bitter cultivars
Pucara	26	69.2	18.4	7.4	41.7	25.0	12.5
Villa Hermosa	24	29.2	33.2	24.7	43.4	23.8	41.3
Chuñunapampa	24	4.2	38.1	42.8	35.6	36.9	30.5
Sotopampa	25	12.0	18.3	20.6	12.3	18.4	1.8
Ccasapata	30	10.0	37.2	38.4	48.5	22.7	23.1
Santa Rosa	25	12.0	18.2	21.1	18.5	13.5	21.5
Ccollpaccasa	25	24.0	15.0	14.5	17.5	13.7	12.5
Huachua	25	0	31.7	14.7	27.9	45.4	35.3
Chopccapampa	50	46.0	13.5	16.2	18.8	7.2	0.7
Limapampa	25	4.0	17.2	13.1	19.8	21.6	4.3
Overall	279	23.3	25.2	24.5	30.6	20.5	22.9

[1] = households

High levels of yield reduction together with cultivar loss explain the need for farmers to acquire seed. A total of 83.2% of the families interviewed for the survey (n=279) had been able to acquire potato seed. An average of 42.5% of combined seed acquisitions for individual households were exclusively coordinated by men, 17.4% exclusively by women and 40.1% by both sexes. Of those farmers having reported cultivar loss 23.6% had not been able to recuperate any of the lost cultivars for the next planting season, 75.3% had recuperated some cultivars, while only 1.1% had been able to acquire all the cultivars they lost.

On average households acquired seed from 2.3 (± 1.3) different sources; some had acquired seed from up to 9 different sources. Table 6.15 provides an overview of the relative importance of specific mechanisms of seed acquisition in 2007 after the frost: donations, monetary acquisition and non-monetary acquisition. Seed from government donations were the most important source of seed in terms of the number of families having benefited from this mechanism (42.9%), followed in importance by monetary acquisitions from regular markets, monetary acquisitions at agricultural fairs, and non-monetary acquisitions through *minka* (payment in kind). It is interesting to note that each of the ten communities had its own unique portfolio and combinations of mechanisms for seed acquisition. While some mechanism were of no importance in some communities they were relevant in others.

The departmental office of the Ministry of Agriculture provided most of the governmental seed donations followed by other institutions such as PRONAMACHCS[2] and the regional government. These institutions mostly purchased seed outside of Huancavelica. Information about seed quality and exact origin was not available to farmers. The government's incapability to provide farmers with clear information about the origin of donated seed fomented suspicions from farmers. They feared that part had been obtained from the coast where disease incidence, particularly of viruses, tends to be high. The suspicion was that intermediaries had bought, reselected and provided consumption potatoes as seed.

The volume and cultivar content of 574 individual seed acquisitions realized by 253 different households was registered. Table 6.16 shows summarized information of the quantities of seed acquired per event of exchange. Very few transactions involving native-bitter cultivars were registered, affirming that sources of supply of this cultivar category are scarce. Each seed acquisition involved on average 66 kg. Yet, a high standard deviation indicates that there were considerable differences in the quantities of seed exchanged per transaction. Overall, farmers acquired slightly more seed of native-floury cultivars (279 transactions; av. 81 kg / transaction) as compared to improved cultivars (286 transactions; av. 53 kg / transaction). Differences between communities concerning the average amount of seed acquired per transaction were modest; the community of Sotopampa was the only notable exception (see table 6.16).

Most households acquired seed of diverse cultivar categories: improved and native-floury cultivars (table 6.17). The registered acquisition of improved cultivars was limited to 5 cultivars: *Yungay* (58.5%), *Canchan* (27.6%), *Perricholi* (12.2%), *Tomasa* (1.0%) and *Mariva* (0.7%). Farmer acquisition of native-bitter cultivars was rare and only involved 2 cultivars: *Siri* (55.6%) and *Manwa* (44.4%). The acquisition of native-floury seed was characterized by higher levels of diversity with 40 cultivars registered. As expected, common commercial cultivars were most commonly acquired: *Larga* (23.9%), *Wayru* (7.4%), *Peruanita* (7.0%) and *Amarilla Runtus* (6.0%). The acquisition of mixed seed lots (*chaqru*) represented only 7.0% of the total number of individual seed acquisitions of native-floury cultivars. The average total number of cultivars acquired per household was 3.0 (± 2.8; table 6.17). This means that although most farmers were able to acquire seed, the overall diversity acquired was modest with relatively few farmers having obtained mixed seed lots and the overall acquired diversity consisting of few distinct cultivars. Nevertheless,

[2] PRONAMACHCS = *Programa Nacional de Manejo de Cuencas Hidrográficas y Conservación de Suelos*; a semi-independent operative branch of the ministry of agriculture.

most farmers (41.7%) did acquire seed of different cultivar categories; improved cultivars predominantly via donations and native-floury cultivars through monetary acquisitions at markets and fairs or through *minka*. Most of the seed acquisitions took place just before and during the start of the planting season in October (17.9%), November (35.0%) and December (27.4%) rather than the initial months after harvest (May till June; 19.7%).

Table 6.15: Relative importance (*) of different mechanisms of seed acquisition between May - December 2007

Community	N[1]	Donation (%)			Monetary Acquisition (%)					Non-Monetary Acquisition		
		GO	NGO	Family	Regular Markets	Agricultural Fairs	Family	Farmer from the community	Farmer from another community	Loan	Barter	Minka: payment in kind
Pucara	26	35.7	-	-	17.9	67.9	-	3.6	3.6	-	-	-
Villa Hermosa	19	68.4	-	10.5	-	78.9	-	-	-	-	-	-
Chuñunapampa	20	60.0	5.0	-	30.0	15.0	5.0	-	-	5.0	-	40.0
Sotopampa	25	96.0	16.0	-	4.0	-	16.0	12.0	4.0	-	8.0	40.0
Ccasapata	24	59.1	4.5	-	40.9	-	18.2	13.6	4.5	-	-	18.2
Santa Rosa	25	-	-	-	4.0	28.0	24.0	4.0	-	-	-	44.0
Ccollpaccasa	25	4.0	4.0	-	40.0	48.0	12.0	12.0	4.0	-	-	8.0
Huachua	22	59.1	4.5	-	40.9	4.5	22.7	4.5	-	-	-	45.5
Chopccapampa	50	12.0	2.0	-	86.0	4.0	6.0	26.0	2.0	-	6.0	-
Limapampa	25	80.0	8.0	-	24.0	32.0	20.0	4.0	8.0	-	-	36.0
Overall	261	42.9	4.2	0.8	34.5	25.7	11.9	10.0	2.7	0.4	1.9	20.7

* = the percentage of households having acquired seed through any of the specific mechanisms; [1] = No. of households

Table 6.16: Quantities of seed exchanged per acquisition

Community	Potato overall (kg)					Improved cultivars (kg)					Native-floury cultivars (kg)					Native-bitter cultivars (kg)				
	N[1]	Av.	SD	Min.	Max.	N[1]	Av.	SD	Min.	Max.	N[1]	Av.	SD	Min.	Max.	N[1]	Av.	SD	Min.	Max.
Pucara	50	52	35	10	155	45	51	35	10	155	5	60	38	25	100	0	-	-	-	-
Villa Hermosa	60	55	31	10	150	43	55	31	10	150	17	55	32	10	100	0	-	-	-	-
Chuñunapampa	38	66	64	2	350	13	64	38	15	150	24	69	76	2	350	1	15	0	15	15
Sotopampa	50	188	686	5	3500	31	49	58	5	285	19	413	1090	5	3500	0	-	-	-	-
Ccasapata	42	49	34	1	150	20	58	32	10	150	21	39	32	1	100	1	100	0	100	100
Santa Rosa	58	46	24	5	150	6	38	18	15	50	51	48	25	10	150	1	10	0	10	10
Ccollpaccasa	76	53	50	5	250	21	45	39	5	150	50	57	56	5	250	5	46	9	30	50
Huachua	63	75	183	3	1000	16	43	35	5	100	47	86	210	3	1000	0	-	-	-	-
Chopccapampa	91	55	47	5	200	61	63	48	5	200	30	40.0	41	5	150	0	-	-	-	-
Limapampa	46	40	35	5	200	30	46	38	10	200	15	31	26	5	100	1	5	0	5	5
Overall	574	66	216	1	3500	286	53	41	5	285	279	81	307	1	3500	9	40	29	5	100

[1] = Number of individual seed acquisitions

Table 6.17: Number and type of cultivars acquired by individual households involved in acquisitions between May - December 2007

Community	N (*)	Number of Different Cultivars Acquired				Type of Cultivars Acquired (%)			
		Av.	SD (±)	Min.	Max.	Exclusively Improved cultivars	Exclusively Native-floury cultivars	Exclusively Native-bitter cultivars	Cultivars from diverse categories
Pucara	26	1.6	0.9	1	4	85.2	0	0	14.8
Villa Hermosa	19	3.1	1.2	1	6	47.4	0	0	52.6
Chuñunapampa	21	2.7	2.8	1	11	23.8	38.1	4.8	33.3
Sotopampa	25	2.1	1.3	1	6	44.0	8.0	0	48.0
Ccasapata	21	2.1	1.2	1	6	38.1	9.5	0	52.4
Santa Rosa	23	3.7	3.6	1	12	4.3	73.9	0	21.7
Ccollpaccasa	25	3.0	1.4	1	6	4.0	32.0	4.0	60.0
Huachua	20	3.6	2.8	1	12	20.0	35.0	0	45.0
Chopccapampa	49	3.6	4.0	1	13	51.0	6.1	0	42.9
Limapampa	24	3.9	3.9	1	12	41.7	8.3	0	50.0
Overall	253	3.0	2.8	1	13	38.2	19.3	0.8	41.7

* = No. of households

6.4 Discussion and conclusions

Distinct cultivar categories and specific cultivars are managed unevenly within the overall farmer seed system of the potato crop while also being subject to different mechanisms for their renewal or replacement. This suggests that differentiation of these cultivar categories and considering them as specific seed system components yields important possibilities for refinement of support to farmer-driven *in-situ* conservation. The particulars of cultivar categories will be discussed around the research questions presented in the introductory section of this article.

It is no coincidence that the number of separate seed lots managed by individual households is the same as the number of fields these households manage (see chapter 4). Farmer seed stores are internally organized into separate seed lots because of their different management requirements in the field. Maintaining the 3 cultivar categories and particular combinations of cultivars physically separated allows farmer to better manage the potato crop in terms of field space (location, size), inputs (fertilizers, pesticides; organic, inorganic), management practices (earliness, tillage system) and end-use (home consumption, sales). Additionally, the organization of seed lots provides insights into the overall structure of infraspecific diversity with an average higher number of separate lots per household being kept of the diverse category of native-floury cultivars and all households storing complete cultivar mixtures (*chaqru*) separately from single cultivar lots. The latter implies that, just as in the field, genetically diverse cultivars are typically concentrated in a combined lot.

Inquiry into seed health, specifically into the presence of potato viruses, offers mixed lessons. The powdery scab (*Spongospora subterranea*) and aphid (*Myzus persicae*) transmitted viruses PMTV, PLRV and PVY were of limited importance with overall infection rates of farmer seed stocks well below 5%. However, APMoV and PVX, transmitted through *Diabrotica* leaf beetles and contact respectively, do show high overall infection rates of 18.1% and 47.0%. Both viruses pose a threat to the seed quality of native potato cultivars under contemporary farmer management. Bertschinger *et al.* (1990) found that overall infection rates of PVX (19.8%) and PLRV (24.1%) in native potato cultivars were relatively widespread compared to PVY (2.2%) and APMoV (1.8%). Our findings coincide for PVX and PVY, but differ considerably for APMoV and PLRV.

Possible strategies to support the improvement of potato seed health for APMoV and PVX within the farmer seed system can include the cleanup and reintroduction of native cultivars, control of vectors, roguing and positive selection. The first strategy would be expensive, have limited potential outreach beyond selected communities (based on data of seed exchange from this study) and probably lack sustainability as long as seed management practices remain unchanged. A partial reduction of *Diabrotica* leaf beetle populations may be achieved through adequate rotations including nonhost plants. Chemical control, although frequently recommended, is no real option considering the financial cost and human health risks. Transmission through contact can potentially be reduced, but a clear understanding by farmers of the benefits will be essential. Simple and applied practices such as roguing and positive selection may also help to effectively reduce infection rates to acceptable levels below 5% (Gildemacher *et al.*, 2007a, 2007b; Hidalgo, 1997).

During years without extreme regional events affecting the overall productivity of potato, seed acquisitions of native cultivars are characterized by transactions involving small quantities of seed, few cultivars, few events of exchange, and movements of seed over short distances within communities and provinces. Annual seed acquisitions of native cultivars are practiced by 25% of the households. So, most households exclusively use home produced seed of native cultivars while those acquiring seed do so to partially renew their seed stocks. Seed provision is dynamic in terms of the average amount of cultivars exchanged per household, volumes handled, number of farmers involved and distances covered by seed flows compared to seed acquisition. About half (48%) of the households in the studied communities provide seed and do so more frequently than acquiring seed. Seed provisions also involve larger volumes and distances compared to seed acquisitions. All this suggests that high-altitude and diversity-rich communities are net seed exporters rather than importers of native cultivars during normal years. Seed acquisitions and provisions during normal years, independently whether they are, typically involve diverse sources including markets, fairs, family and other farmers rather than governmental or non-governmental agencies. Exchange through sales is predominant, but transactions through barter, gifts and payment in kind are also important. It is likely that the socioeconomic conditions of farmers in terms of poverty and availability of cash influence the seed exchange mechanisms they can access.

Even during normal years, uncommon native cultivars are exchanged infrequently and only few farmers provide them. The former contradicts common farmer interest as many look for new or lost cultivars rather than for common cultivars already in stock. Collectively the communities maintain at least 400 genetically and morphologically distinct native cultivars (see chapter 2). The maximum total annual regional amount of distinct cultivars being exchanged was 57 (seed acquisition 2004); this translated into 14% of the total cultivar diversity. Most are native-floury rather than native-bitter cultivars. The latter are almost exclusively maintained and reproduced at the household level. Uncommon native-floury cultivars are not actively marketed by farmers who maintain them. However, households wishing to acquire diverse native-floury cultivars have a chance to do so when they know the right specialist channels, such as vendors providing *chaqru* at markets or farmers willing to exchange. The participation of the formal regulated system in seed exchange of native cultivars is minimal. This study shows that the efficiency of the farmer seed system in terms of its capacity to annually widely supply and distribute infraspecific diversity is restricted. However, in the long run, the farmer seed system generally seems efficient at maintaining overall infraspecific diversity. This is supported by the fact that no evidence of genetic erosion exists (see chapter 2) and that farmers in Huancavelica still maintain early-generation improved cultivars disseminated in the 1950's.

Regular markets typically provide relatively large volumes of seed of selected improved and native-floury potato cultivars rather than infraspecific diversity. Exchanges of these well-known cultivars are frequent and involve large quantities. Market originating seed flows have a wide outreach, covering all provinces within Huancavelica. Indeed, the strength of regular markets as seed suppliers resides in their decentralized capacity to supply and widely distribute selected cultivars with commercial demand while their weakness resides in the limited infraspecific diversity and quality guarantee they offer. Uncommon cultivars are typically only offered by a few vendors while their transactions are infrequent involving small quantities of seed. Complete native-floury cultivars mixtures (*chaqru*) are offered by a few selected vendors while seed of native-bitter cultivars are generally unavailable. Regular potato markets in the rural areas of central Peru are mostly consumption markets rather than seed markets.

Biodiversity seed fairs are an institutional innovation which potentially changes the way in which transactions occur. The original intention of the fairs was to enhance broad diffusion of native cultivars among farmers. Indeed, contemporary fairs almost exclusively target native-floury and native-bitter cultivars. However, findings of this research suggest that the biodiversity seed fairs are not necessarily doing what they were designed for. Participation at the fairs is often restricted to a select group of recognized farmers. Seed exchange is not an important motive for farmers to participate. Rather, it is prestige, recognition or the possibility of winning a prize which motivates participants. In practice, the frequencies of seed exchange are low. Not only do few farmers exchange seed, those who exchange generally do so with a few uncommon cultivars and small volumes. The number of cultivars and volumes exchanged, though potentially interesting for a collector, are generally not significant for those wishing to acquire seed for planting large areas. The strength of biodiversity seed fairs resides in the impressive amount of native cultivars farmers put on display. Seed fairs are an excellent thermometer to monitor overall genetic diversity. Yet, their weakness resides in selectiveness toward individuals rather than farmers communities and incapacity to create an environment which stimulates seed exchange. Organizers of fairs could promote wider participation and seed exchange by emphasizing the participation of communities rather than individual farmers, including indicators of seed exchange into the evaluation criteria, and by providing incentives for most participants rather than for the top-three "conservationist" farmers alone.

Inquiry into the dynamic seed system response to seed stress provides diverse lessons. The 2007 February frost severely affected productivity of the potato crop and led to seed stress as a result of the loss of cultivars and acute shortages of planting material. Cultivar loss was predominantly a consequence of severe crop failure rather than farmers not being able to save seed from being consumed. Contrary to normal years, when seed acquisitions from governmental organizations were of little importance for farmers, state-organized donations were regionally the most important source of seed after the frost. Governmental organizations reached numerous communities and households with donations. This in itself does not necessarily imply that the farmer seed system was unable to cope with seed stress. Regular markets, agricultural fairs, payment in kind (*minka*), acquisitions from family and community members remained important sources of seed. These sources are also commonly used during normal years, but became more important during the period with seed stress. Each community showed a unique portfolio and combination of mechanisms of seed acquisition. Indeed, in all communities a diversity of mechanisms were employed to regain seed. Considering the regional shortage of planting material, the frequency of seed exchanges and sources used suggest impressive resilience of the farmer seed system. The system was, at least partially, able to attend local demands within the first year after the stress and restore part of the cultivar portfolios of individual households.

An average farmer in the studied communities annually dedicates an area of 5,609 m² to potatoes (see chapter 4). This translates into a minimal annual demand of 1,400 kg of seed. In 2007, after the season with severe frost incidence, the average household only saved 25.2% of the potato seed they would normally store. This means a minimum of 350 kg per household and an average household deficit of 1,050 kg. On average households acquired seed from 2.3 different sources, exchanging 66 kg per transaction. The average household thus acquired 152 kg of seed, leaving an overall deficit of 898 kg representing 64% of the total demand. This simple calculation shows that for many households the amount of seed acquired after the frost must have been insufficient to meet the normal demand, even though the real seed deficit may have been less and differences between households exist. This suggests that both the government donations and the regional farmer seed system were unable to provide sufficient quantities of seed. In addition, government and other organizations donated mostly seed of improved cultivars.

Seed security is determined by availability, access and utilization (Remington *et al.*, 2002). Seed was regionally available and accessed by farmers through both monetary and non-monetary purchase. However, it was insufficiently available and/or accessible to fulfill the total regional demand. Government seed donation acted on the notion that seed was regionally unavailable, therefore importing seed from other parts of Peru. Different mechanisms providing access to the diverse seed sources are determined by a household's relative wealth, its safety network and the kind of seed required. In turn each source in governed by different institutions (rules of the game) affecting access. This reality results in uneven practical responses by households according to their possibilities. Most households had to rebuild seed stocks of native-bitter and uncommon native-floury cultivars from the scarce home produced seed which could be saved. Native-bitter and uncommon native-floury cultivars were not commonly supplied through any of the regular mechanisms acquisition. The bulk of cultivars acquired by farmers were well-known commercial improved and native-floury cultivars. Utilization was an issue for donated seed. Doubts about the quality and origin of seed donations motivated some families to eat rather than to plant the tubers. Resilience of the farmer seed system was incomplete as households were only able to restore part of their original seed stocks, both in terms of volumes and cultivar portfolios. Indeed, several seasons may be needed for households to fully recover their seed stocks. This also means that repeated regional shocks may indeed impede the seed system to fully recover.

7 The role of biodiverse potatoes in the human diet in central Peru: nutritional composition, dietary intake and cultural connotations[1]

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Abstract
Potato is the indigenous mainstay within the high-altitude food system of Huancavelica, Peru, where farmers grow numerous potato cultivars. This study investigates the role of infraspecific diversity of native-floury, native-bitter and improved cultivars in the human diet of Quechua Indians. The dry matter, energy, protein, iron and zinc content of 12 native-floury and 9 native-bitter cultivars was determined (fresh, stored, and freeze-dried). The contribution of the potato and main cultivar categories to the dietary intake of energy, protein, iron and zinc was established during two contrasting periods of overall food availability. Additionally, general cultural connotations concerning the consumption of multiple cultivars and potato as a class marker were investigated. A combination of complementary research methods was applied in the field and the laboratory.

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Results suggest that *in-situ* conserved infraspecific diversity can make a valuable contribution to enhanced nutrition. Several native-floury cultivars contain higher contents of specific nutrients (protein, iron) than those commonly reported as representative for native potato cultivars. Storage does not affect the nutritional quality of native-floury cultivars very significantly, while traditional freeze-drying of native-bitter cultivars reduces protein and zinc content considerably. The potato contributes positively to the nutritional balance and the recommended requirements for energy, protein, iron and zinc of women and children during periods of both food abundance and scarcity. Native-floury and improved cultivars complement each other providing nutrients during different periods of the year. The consumption of diverse potato cultivars is entangled with cultural constructions of meals and local perceptions of preference traits and quality. The potato itself, as a food item, is no socioeconomic class marker. However, certain dishes or products and the overall cultivar diversity grown and used by a household do mark perceptions of relative wealth.

7.1 Introduction

7.1.1 Food systems and biodiversity

Food systems encompass activities and knowledge related to the production, acquisition, and utilization of foods that affect human nutrition and health (Kataki and Babu, 2002). The Andean food system typically makes use of numerous indigenous plant and animal species which are little known outside their centre of origin (FAO, 1992; Hernández and León, 1994; NRC, 1989). The rural Andean food system in central Peru is further characterized by mixed crop-livestock production systems (Morlon, 1996b), the use of traditional processing technologies (Horkheimer, 1973; Yamamoto, 1988; Werge, 1979), an indigenous food culture, cuisine and related indigenous knowledge (Fries, 2001; Hurtado, 2000; Olivas Weston, 2001), frequent rural household involvement in off-farm employment and consequent ability to purchase "exotic" food stuffs (Fiege, 2005; Mayer, 2002), and the presence of external food assistance programs addressing food insecurity and malnutrition (Delgado, 1991; Stifel and Alderman, 2003).

Links drawn between biodiversity and nutrition generally focus on species diversity (Toledo and Burlingame, 2006). Relatively little attention has been given to the potential role of infraspecific diversity and its contribution to food security (Thrupp, 2000). Diets characterized by nutritional diversity with food intake from a variety of sources, including different crop species and cultivars, are likely to be more balanced compared to monotonous diets (Johns, 2002). It is well established that the cultivated potato is both genetically diverse and a mainstay of the rural diet in the Andean highlands (Brush, 2004; Graham *et al.*, 2007). Farmers in Huancavelica, central Peru, typically consume diverse fresh and processed native potato cultivars. However, little is known about their nutritional composition, contribution to dietary intake of energy, protein and minerals, and cultural connotations as a food source.

7.1.2 Nutritional composition

Potato tubers contain calories, quality protein, minerals, and the water-soluble vitamins C and complex B (Horton, 1987; True *et al.*, 1978; Woolfe, 1986). Variation in dry matter content, depending on the variety or growing environment, results in a range of energy contents. On average fresh potatoes are reported to contain 80 kcal of energy per 100 g (Woolfe, 1987). Zavaleta *et al.* (1996) report average values of 97 and 103 kcal per 100 g of fresh "white" potato (improved; presumably *S. tuberosum* subsp. *tuberosum*) and "yellow" potato (native-floury; presumably *S. goniocalyx*) respectively. It is generally accepted that both fresh and boiled potatoes contain about 2% of crude protein on a fresh weight basis (Munshi and Mondy, 2006; Woolfe, 1987). The quality of potato protein is high with a favourable amino acid balance consisting of histidine, isoleucine, leucine, lysine, methionine, cysteine, phenylalanine, tyrosine, threonine, tryptophan and valine (Munshi and Mondy, 2006; Woolfe, 1987).

Potatoes contain important minerals, including iron and zinc. Fresh peeled potato contains 0.167 - 0.538 mg of iron and 0.170 - 0.390 mg of zinc per 100 g of fresh weight, depending on the specific genotype (True *et al.*, 1979; Zavaleta *et al.*, 1996). Screening of 37 native potato cultivars in different environments for iron and zinc content revealed significant variation ranging from 9 to 37 mg Fe kg^{-1} and 8 to 20 mg Zn kg^{-1} (dry weight basis; peeled) due to environments and genotype by environment interaction (Burgos *et al.*, 2007). Potato is particularly rich in vitamin C (ascorbic acid) with ranges of 7.8 - 36.1 mg per 100 g of fresh weight (Woolfe, 1987). High ascorbic acid and low phytate content enhance iron bioavailability (Fair Weather-Tait, 1983; Scurrah *et al.*, 2007). Cooking results in significant losses of ascorbic acid, but the effect on protein and mineral content seems minimal (Horton, 1987). The vitamin B complex of potato contains varying levels of thiamine (B1), riboflavin (B2), niacin (B3), pyridoxine (B6) and folic acid (B9). Cultivars with colored tuber flesh also contain varying levels of anthocyanins which act as antioxidants in the human diet (Brown, 2005; Fossen and Anderson, 2000; Jansen and Flamme, 2006; Reyes *et al.*, 2005).

Freeze-dried potatoes, commonly known as *chuño* in central Peru, can be conserved for several years. Freeze-drying is an indigenous Andean technology of pre-Inca origin (López Linage, 1991; Valdizán and Maldonado, 1922). The process is used to minimize the glycoalkaloid content of native-bitter cultivars belonging in their majority to the species *S. juzepczukii, S. curtilobum* and *S. ajanhuiri*. However, selected cultivars belonging to other species such as *S. tuberosum* subsp. *andigena* and *S. stenotomum* are also occasionally freeze-dried (Burgos *et al.*, forthcoming). Freeze-drying makes use of severe frosts at night alternated with high daytime levels of solar radiation and low levels of relative humidity during the months of June and July when temperatures are lowest (Woolfe, 1987). Stages and techniques of tuber processing include: exposure to frost at night and sun during the day, removal of liquid by treading with bare feet, an optional stage of immersing these semi-processed tubers in a pond or river with running water for several days, and exposure to sun for drying (Christiansen, 1967; Condori Cruz, 1992; Fonseca *et al.*, 2008; Mamani, 1981). Depending on the specific techniques the final product can take two basic forms: *chuño blanco* (white *chuño*; also known as *tunta* or *moraya*) or *chuño negro* (black *chuño*). Tubers used for processing white *chuño* are immersed in running water in between treading and drying while tubers used to prepare black *chuño* are dried directly after treading without exposure to water (Yamamoto, 1988). The average energy, protein, iron and calcium content of 100 g of white *chuño* is reported to be 323 kcal, 1.9 g, 3 mg and 92 mg and that of black *chuño* 333 kcal, 4.0 g, 0.9 mg and 44 mg (Zavaleta *et al.*, 1996). Between 18 and 41% of protein is lost during the elaboration of *chuño* (Christiansen, 1978).

Relatively little is known about the nutritional composition of different native-floury and native-bitter potato cultivars and variability within *in-situ* conserved cultivar stocks. The same is true for the effect of processing (cooking, freeze-drying) and storage on the nutritional content of diverse potato cultivars. What is the energy, protein, iron and zinc content of commonly consumed native-floury and native-bitter potato cultivars? How is the nutritional composition of fresh native-floury cultivars influenced by cooking and storage? What is the nutritional composition of unprocessed boiled tubers compared to boiled *chuño* of native-bitter cultivars as commonly consumed by highland Indians?

7.1.3 Nutrition and dietary intake

Huancavelica's rich genetic diversity within the potato crop paradoxically coincides with high levels of poverty and malnutrition. The department of Huancavelica is often considered the poorest of Peru's 24 departments (Luna Amancio, 2008; MEF, 2001; Rubina and Barreda, 2000). In

2001, 74.4% of the total population was considered to be extremely poor (INEI, 2002). The Andean countries, particularly Peru and Bolivia, have high rates of stunting (under height for age) for children less than 5 years of age (UNDP, 2008). Micronutrient deficiency, particularly of iron (Fe), zinc (Zn) and various vitamins, is considered especially severe in term of the number of people affected compared to energy and protein shortcomings in the human diet (Graham *et al.*, 2007; Mason and Garcia, 1993; Welch and Graham, 1999). Chronic malnutrition (stunting) affects more than 50% of children under 5 years of age in Huancavelica while acute malnutrition affects slightly less than 1% (table 7.1). Both chronic and acute malnutrition of this age group increased between 1996 and 2000.

Table 7.1: Under five years of age malnutrition for Peru's main Andean departments (1996/ 2000)

Department	% Children with chronic malnutrition (height for age)				% Children with acute malnutrition (weight for height)			
	1996 census		2000 census		1996 census		2000 census	
	Severe	Total	Severe	Total	Severe	Total	Severe	Total
Huancavelica	19.6	50.3	22.2	53.4	-	0.5	-	0.9
Ancash	9.2	25.1	10.2	34.5	0.2	0.7	-	0.4
Apurimac	17.2	46.9	13.6	43.0	-	0.8	0.3	2.0
Arequipa	3.3	12.4	2.3	12.3	-	1.0	-	0.3
Ayacucho	14.1	43.2	12.1	33.6	-	0.8	0.4	3.0
Cajamarca	12.3	38.7	15.4	42.8	0.8	2.1	0.2	1.4
Cusco	14.5	40.9	14.0	43.2	0.8	1.9	0.6	1.6
Huánuco	10.0	28.3	15.3	42.8	0.4	2.7	0.2	1.1
Junin	12.1	35.5	10.5	31.3	0.2	1.3	0.7	1.8
Pasco	19.3	47.2	5.0	26.4	0.3	1.8	-	2.6
Puno	5.0	23.0	5.9	29.7	0.7	1.9	0.3	0.7

Sources: INEI, 1996; INEI, 2000

Adequate nutrient coverage through a balanced diet is important, especially for vulnerable groups such as children en women at fertile age. The potato is a mainstay of the Peruvian highland diet and, depending on the specific community and season, may cover between 9 to 78% of the total daily food intake (Mazess and Baker, 1964; Picón-Reátegui, 1976). A recent food consumption survey in Huancavelica, conducted by Peru's National Health Institute and National Center for Food and Nutrition (INS-CENAN, 2003) during the main annual harvest time (May - June), shows that potato is consumed on a daily basis by 100% of adult women (average 820 g / day) and 70% of children between 12 and 35 months of age (180 g / day). Yet, dietary intake and stress in the Peruvian Andes is season-dependent (Graham, 2003a). Therefore it is important to compare periods of relative food abundance with periods of relative scarcity.

Potato is generally treated as a uniform category when specified in food intake studies (e.g. Estrada and Dueñas, 1992). The relative contribution of improved, native-floury and native-bitter cultivars (processed in *chuño*) to the rural Andean diet, during different periods of the year, is unknown. What is the relative contribution of potato and the different cultivar categories to the highland diet? What are the differences between the periods of relative food abundance versus scarcity? Do native and improved cultivars compete within the diet or rather complement each other? Does overall food intake satisfy the requirements of the vulnerable population (mothers and children)?

7.1.4 Cultural connotations

It is generally well-accepted that the diversity of culturally embedded uses of infraspecific diversity is particularly rich in the centre of origin of a crop species, whether it concerns rice in Asia (Ohnuki-Tierney, 1994), corn in Mexico (Coe, 1994; Sandstrom, 1991), or potato in the Andes (Johnsson, 1986; Weismantel, 1988). If a single potato cultivar would satisfy all the food preferences and requirements of an Andean household then there would be little need for them to grow numerous cultivars. Therefore the use of potato genetic diversity, especially for human consumption, is arguably an important motive underlying farmer-driven *in-situ* conservation and often entangled with particular preference traits and local perceptions of quality. However, the cultural essence underlying variety choice is often hidden and difficult to capture through conventional research methods (Brush, 2004).

Food and cuisine are among the strongest of ethnic and socioeconomic class markers (Weismantel, 1988). Certain foods are typically associated with being poor or non-poor within particular cultural settings. The knowledge of food preparation and purchase, etiquettes of consumption and sharing, beliefs associated with certain foods, and how this knowledge itself is transferred from one generation to the next are important components of the food system. Why do Quechua farmers in central Peru typically consume multiple cultivars rather that a single one? Is potato just a simple staple food or is it also a component of a more elaborate cuisine? What are the most notable cultural particulars of potato and its infraspecific diversity within Huancavelica's food culture?

7.2 Materials and methods

7.2.1 Nutritional composition

The composition of 12 frequently cultivated and consumed native-floury potato cultivars from the department of Huancavelica (Peru) was determined (table 7.2). Tubers of each native-floury cultivar were obtained from a single source (farmer) and environment (field). Analysis to determine the dry matter, gross energy, crude protein, iron (Fe) and zinc (Zn) content of fresh and boiled tuber samples of the cultivars was conducted after harvest. Additionally, analysis was conducted after 3 and 5 months of storage under local conditions (only for boiled tuber samples). Storage was done in a traditional farmer's store on a "*troje*" (bed with straw) at 4,100 meters above sea level. The average monthly temperature during storage fluctuated between a minimum of 6.4 ºC (August) and maximum of 9.6 ºC (July) while the average monthly relative humidity fluctuated between a minimum of 48.1% (July) and a maximum of 73.4% (November).

Table 7.2: Common native-floury potato cultivars used for nutritional analysis

Cultivar	Species	Ploidy
'Allqa Palta'	*S. tuberosum* subsp. *andigena*	$2n=4x=48$
'Ayrampu'	*S. tuberosum* subsp. *andigena*	$2n=4x=48$
'Sortijillas'	*S. tuberosum* subsp. *andigena*	$2n=4x=48$
'Qori Markina'	*S. tuberosum* subsp. *andigena*	$2n=4x=48$
'Ajo Suytu'	*S. chaucha*	$2n=3x=36$
'Puka Wayru'	*S. chaucha*	$2n=3x=36$
'Sirina'	*S. chaucha*	$2n=3x=36$
'Ritipa Sisan'	*S. chaucha*	$2n=3x=36$
'Chiqchi Pasña'	*S. goniocalyx*	$2n=2x=24$
'Peruanita'	*S. goniocalyx*	$2n=2x=24$
'Runtus'	*S. goniocalyx*	$2n=2x=24$
'Yana Puqya'	S. *stenotomum*	$2n=2x=24$

Additionally, the composition of 9 common native-bitter cultivars was determined (table 7.3). These cultivars are frequently used for traditional freeze-drying in Huancavelica. Tubers of each native-bitter cultivar were obtained from single source (farmer) and environment (field). Analysis to determine the gross energy, crude protein, iron (Fe) and zinc (Zn) content of boiled unprocessed tuber samples was conducted right after harvest while analysis of boiled white *chuño* samples was conduced after freeze-drying. Traditional freeze-drying of white *chuño* of each cultivar was done by a farmer from the community of Villa Hermosa under uniform conditions following procedures as commonly practiced in Huancavelica. These procedures were: a. exposure to frost at night and sun during the day (3 days), b. removal of liquid by treading with bare feet (½ day), c. submergence of treaded tubers in a pond with water (5 days), d. exposure to sun for drying (5 days).

Table 7.3: Common native-bitter potato cultivars used for nutritional analysis

Cultivar	Species	Ploidy
'Yana Manwa'	*S. tuberosum* subsp. *andigena*	$2n=4x=48$
'Yuraq Lui'	*S. tuberosum* subsp. *andigena*	$2n=4x=48$
'Kumpus Siri'	*S. juzepczukii*	$2n=3x=36$
'Yuraq Siri'	*S. juzepczukii*	$2n=3x=36$
'Yana Siri'	*S. juzepczukii*	$2n=3x=36$
'Puka Qanchillu'	*S. juzepczukii*	$2n=3x=36$
'Yuraq Waña'	*S. curtilobum*	$2n=5x=60$
'Yana Waña'	*S. curtilobum*	$2n=5x=60$
'Ipillu Culebra'	*S. stenotomum*	$2n=2x=24$

Three samples per cultivar and treatment, each representing one repetition, were prepared. The following tuber samples were prepared for each of the 12 native-floury cultivars per treatment: a. fresh tubers after harvest, b. boiled tubers after harvest, c. boiled tubers after 3 months of storage, d. boiled tubers after 5 months of storage. The following tuber samples were prepared for each of the 9 native-bitter cultivars per treatment: a. boiled fresh (unprocessed) tubers after harvest, b. boiled tubers of white *chuño* after freeze-drying. Prior to cooking tubers were washed and rinsed with still water. Fresh and boiled tubers were peeled and cut longitudinally into 4 parts. From 2 opposite sides a 50 g sample was obtained and dried in an oven at 80 ºC during 24 hours; then weighed, pulverized, put in kraft paper bags and sent to Waite Analytical Services[2] for the determination of iron and zinc content. Samples were digested (0.6 g; 140 ºC; 70% HNO3/ HClO4) and subjected to inductively coupled plasma optical emission spectrometry (ICO-OES; analyzer ARL 3580B ICP) for analysis of iron, zinc and aluminium content. Aluminium was used as an indicator of possible iron contamination (soil, dust). The remaining 2 opposite sides of each tuber were used to prepare samples for proximal analysis. Slices were taken from each tuber section (total 100 g) and each sample put in polyethylene bags, frozen at -20 ºC and dried in a lyophilizer. Dry samples were weighed, pulverized, stored in plastic bags and sent for analysis to the nutrition laboratory of the National Agrarian University "La Molina" (Lima, Peru). Complete proximal analysis of samples was done following standard procedures as described in AOAC (1990). A completely randomized factorial design was applied and analysis of variance and simple effects was conducted with SAS 8.2 software[3] . Comparison of averages was done using Duncan's multiple range test.

[2] Nutrition group, School of Agriculture, Food and Wine, University of Adelaide, Australia.
[3] SAS/STAT software. Institute Inc. OnlineDoc®, Version 8.2, Cary, NC: SAS Institute Inc. 1. 1999.

7.2.2 Nutrition and dietary intake

A food intake study was conducted in order to quantify and characterize the contribution of the potato and others food sources to the diet of children between 6 and 36 months of age and their mothers. The study was conducted in 6 highland communities: Villa Hermosa, Pucara, Dos de Mayo, Libertadores, Pongos Grande and Allato. Research was conducted during two contrasting periods of overall food availability: a. after the main harvest (period of relative abundance; May-June 2004), b. seven months after the main harvest (period of relative scarcity; January-February 2005).

A team of female, Spanish and Quechua speaking, fieldworkers from the research communities was trained during a 2-week period in order to standardize procedures for handling scales, correct weight measurements of food items, use of registration forms, conducting surveys, and recognition of predominant native potato cultivars. An agreement of prior informed consent was signed with each of the participating households. The specific method consisted of direct measurement of food intake by weight during a 24 hour period for each household (mothers and children under 3 years of age; Graham, 2003b). During the period of relative abundance this led to a sample of 76 households (19.4% of the total number of households; table 7.4). During the period of relative scarcity the sample consisted of 77 households (19.7% of the total number of households). Additionally data to determine the overall nutritional status of children from the 6 research communities was collected at schools: age, weight, height. A total of 340 children with ages between 4 and 16 years participated.

The conversion of food item intake to nutritional contribution (energy, protein, iron and zinc) was based on food composition tables developed by the Institute of Nutrition Research (IIN, Lima, Peru). The nutritional value of specific native potato cultivars was used when available from our own research. Otherwise, average values were assigned to native potato cultivars with unknown nutritional compositions. Nutritional values of specific improved cultivars were taken from IIN´s food composition tables. Estimated levels of nutrient intake were compared against age-based internationally recommended levels of intake (FAO/WHO, 2002; FAO/WHO/UN, 2004; Institute of Medicine, 2002). Raw data from the intake study were codified and ranges and values checked with Microsoft Visual fox pro 6.0 software. Data analysis was conducted with SPSS 11.0 software[4]. Indices of malnutrition (weight/age; weight/height; height/age) were calculated using Anthro 1.02 software[5].

Table 7.4: Distribution of the sample size by period, community and target group

Community	Period of Abundance				Period of Scarcity			
	Women		Children		Women		Children	
	n	%	n	%	n	%	n	%
Villa Hermosa	16	21.1	16	21.3	13	16.9	12	15.4
Pucara	11	14.5	10	13.3	16	20.8	16	20.5
Dos de Mayo	8	10.5	8	10.7	7	9.1	8	10.2
Libertadores	16	21.1	16	21.3	18	23.4	18	23.1
Pongos Grande	7	9.2	7	9.3	8	10.4	8	10.3
Allato	18	23.7	18	24.0	15	19.5	16	20.5
Total	76	100	75	100	77	100	78	100

4 SPSS. Release 11.0.01. Standard version. Copyright SPSS Inc. 2001.

5 Anthro 1.02. Nutrition Division. Center for Disease Control (USA) in collaboration with the Nutrition Unit of the World Health Organization (WHO). Atlanta, 1990.

7.2.3 Cultural connotations

Research was conducted in 8 communities: Huayta Corral, Tupac Amaru, Villa Hermosa, Pucara, Dos de Mayo, Libertadores, Pongos Grande and Allato (see chapter 1). Selected cultural annotation of the highland diet were investigated, particularly of cultural elements underlying the consumption of biodiverse potatoes rather than a single cultivar and the local recognition of food items and potato as class markers. The study of these cultural annotations was certainly not exhaustive; rather it tried to capture the most obvious cultural elements.

A variety of methods was used, including participant and ethnographic observation, surveys, and workshops. Participant and ethnographic observation was conducted between 2003 and 2006 (Atkinson *et al.*, 2007; Jorgensen, 1989; Spradley, 1980). The consumption and use of diverse potato cultivars was observed in numerous occasions, including in the kitchen domain, at harvests and/or at special occasions. Participatory poverty analysis workshops and surveys were conducted following an adapted "stages of progress" methodology (see Krishna, 2004; Krishna *et al.*, 2004, 2006). Workshops were conducted in each community and in total 256 adult community members participated. In total 236 surveys were conducted with adult men and women belonging to households classified as being poor or non-poor by local criteria. Surveys were conducted by a previously trained team of Quechua speaking fieldworkers. Training was done in Huayta Corral (see Fiege, 2005); therefore results from this community are not included. The study considered different aspects of poverty, yet for the purpose of this article only information related to selected food systems is used.

7.3 Results

7.3.1 Nutritional composition

Fresh and boiled native-floury cultivars after harvest

The dry matter content (%) of the 12 native-floury potato cultivars fluctuated between 20.8 - 38.3% and 24.7 - 33.0% for fresh and boiled tubers respectively. Differences between cultivars concerning their dry matter content are significant ($p>0.01$; table 7.5). Analysis of variance (ANOVA) indicates that the interaction cultivar x treatment (fresh / boiled) is significant for dry matter content ($p>0.01$). Analysis of simple effects reveals that this is particularly so for the cultivars: *Ayrampu*, *Sortijillas*, *Ritipa Sisan* (table 7.6).

Table 7.5: Analysis of variance for the nutrient content of fresh and boiled tubers (directly after harvest)

Source	df	Dry matter	Energy[a]	Protein	Iron[a]	Zinc
Cultivar	11	45.32 **	1.0×10^{-4} **	10.31 **	0.092 **	15.84 **
Treatment[1]	1	2.06	1.4×10^{-6}	0.51	0.000	0.79
Treat. x cult.	11	24.35 **	1.4×10^{-6}	0.27	0.002	1.74
Error	48	1.71	7.1×10^{-6}	0.42	0.001	1.29
Total	71					
CV	4.6	0.l	7.7	2.9	9.4	
Mean	28.64	381.93	8.37	17.76	12.13	
R^2	0.90	0.78	0.86	0.94	0.77	

[1] = fresh or boiled; ** $p>0.01$; [a] = data transformed to Log^{10}

No significant differences were encountered for energy, protein, iron and zinc content of fresh versus boiled potatoes (table 7.5). Yet, significant differences ($p>0.01$) between the different native-floury cultivars were encountered for gross energy, protein, iron and zinc content (table 7.6). The gross energy content of cultivars fluctuated between 374.8 - 386.2 kcal / 100 g and 96.33 - 123.2 kcal / 100 g on dry and fresh weight basis respectively (table 7.6). The crude protein content fluctuated between 6.1 - 10.7 g / 100 g and 1.8 - 3.0 g / 100 g on dry and fresh weight basis respectively. The cultivars *Runtus* and *Yana Puqya* presented the highest protein content, both on dry and fresh weight basis. The iron content of the cultivars varied between 9.9 - 23.8 mg / kg and 0.3 - 0.7 mg / 100 g on dry and fresh weight basis respectively. The aluminium content of all samples was low (< 6 mg / kg) indicating there was no iron contamination from soil residues. The cultivar *Runtus* had the highest iron content on dry weight basis while *Chiqchi Pasña* showed the highest content on fresh weight basis. Zinc content fluctuated between 9.3 - 15.4 mg / kg and 0.3 - 0.4 mg / 100 g on dry and fresh weight basis respectively. The cultivar *Yana Puqya* showed the highest zinc content, both on dry and fresh weight basis.

Table 7.6: Dry matter, gross energy, crude protein, iron and zinc content of native-floury potato cultivars from Huancavelica

	Dry Matter (%)		Gross Energy[1] (kcal / 100 g)		Crude Protein[1] (g / 100 g)		Iron[1]		Zinc[1]	
	Fresh	Boiled	DWB[2]	FWB[3]	DWB[2]	FWB[3]	DWB[2] (mg/kg)	FWB[3] (mg/100g)	DWB[2] (mg/kg)	FWB[3] (mg/100g)
'Allqa Palta'	27.31 ± 0.74	28.71 ± 1.69	384.33 ± 1.03	109.67 ± 6.25	7.09 ± 0.45	2.02 ± 0.18	9.90 ± 1.08	0.28 ± 0.03	12.47 ± 1.51	0.35 ± 0.05
'Ayrampu'	38.30 ± 1.42	29.63 ± 1.71	382.00 ± 1.26	118.17 ± 13.73	8.21 ± 0.70	2.51 ± 0.12	18.26 ± 2.31	0.63 ± 0.15	12.40 ± 1.07	0.43 ± 0.09
'Sortijillas'	20.79 ± 0.71	29.98 ± 0.80	381.67 ± 0.52	111.17 ± 5.12	6.06 ± 0.52	1.76 ± 0.12	10.11 ± 0.67	0.26 ± 0.04	12.25 ± 1.50	0.31 ± 0.05
'Qori Markina'	24.43 ± 2.16	25.85 ± 0.59	378.83 ± 1.47	96.33 ± 3.08	9.58 ± 0.88	2.44 ± 0.17	18.79 ± 0.71	0.47 ± 0.04	11.01 ± 0.39	0.28 ± 0.02
'Ajo Suytu'	30.37 ± 1.05	30.34 ± 0.94	381.83 ± 0.98	123.17 ± 10.42	8.13 ± 0.66	2.62 ± 0.27	17.22 ± 2.15	0.52 ± 0.06	9.32 ± 0.93	0.28 ± 0.02
'Puka Wayru'	29.45 ± 0.56	28.13 ± 1.74	382.50 ± 1.05	111.33 ± 5.85	7.69 ± 0.52	2.23 ± 0.11	19.78 ± 1.34	0.57 ± 0.02	11.16 ± 0.91	0.32 ± 0.02
'Sirina'	28.47 ± 1.55	29.56 ± 1.14	382.67 ± 2.80	112.67 ± 9.46	8.68 ± 0.52	2.56 ± 0.20	18.59 ± 1.73	0.54 ± 0.03	13.98 ± 1.52	0.41 ± 0.04
'Ritipa Sisan'	28.67 ± 0.51	33.00 ± 1.11	382.83 ± 1.72	118.67 ± 7.69	7.75 ± 0.38	2.41 ± 0.19	18.39 ± 1.31	0.56 ± 0.05	10.71 ± 0.36	0.33 ± 0.02
'Chiqchi Pasña'	31.33 ± 1.61	30.48 ± 2.57	386.17 ± 1.47	121.00 ± 8.22	9.18 ± 0.65	2.87 ± 0.13	22.39 ± 2.73	0.72 ± 0.07	12.31 ± 2.28	0.38 ± 0.06
'Peruanita'	30.05 ± 0.91	30.43 ± 2.07	382.67 ± 1.21	118.50 ± 2.43	7.45 ± 0.66	2.30 ± 0.18	14.18 ± 0.83	0.43 ± 0.03	11.22 ± 0.88	0.34 ± 0.02
'Runtus'	25.41 ± 0.51	24.70 ± 0.44	374.83 ± 0.98	103.50 ± 6.69	10.67 ± 0.68	2.95 ± 0.26	23.82 ± 1.81	0.60 ± 0.05	13.33 ± 0.45	0.34 ± 0.01
'Yana Puqya'	26.96 ± 0.67	25.91 ± 0.37	382.83 ± 0.75	108.83 ± 7.28	10.00 ± 0.83	2.84 ± 0.24	21.68 ± 158	0.57 ± 0.04	15.44 ± 0.93	0.41 ± 0.02

[1] = values for boiled tubers; [2] = Dry Weight Basis; [3] = Fresh Weight Basis

Boiled native-floury cultivars after storage

The interaction cultivar x storage time was significant ($p>0.05$) for the dry matter content of boiled tubers (table 7.7). Analysis of simple effects indicates that the following cultivars significantly increased their dry matter content during storage: *Ayrampu* (T0=29.6%, T1=29.7%, T3=33.1%), *Ritipa Sisan* (T0=32.0%, T1=29.7%, T2=33.7%) and *Peruanita* (T0=30.4%, T1=32.0%, T2=35.7%). One cultivar significantly diminished its dry matter content during storage: *Sortijillas* (T0=30.0%, T1=19.6%; T2=21.0%). Increase of dry matter during storage can occur through water loss (evaporation) while a decrease in dry matter can be assigned to a combination of low rates of evaporation and high rates of degradation of starch. No significant differences concerning the dry matter content during storage were encountered for the other 8 native-floury cultivars.

Variation in the gross energy content during storage depends on the specific cultivar with analysis of simple effects indicating significant differences for the cultivars *Runtus* (T0=375 kcal / 100g; T1=380 kcal / 100g; T2=360 kcal / 100g) and *Peruanita* (T0=382 kcal / 100g, T1=386 kcal / 100g, T2=387 kcal / 100g). No significant differences concerning energy content were encountered for the other 10 native-floury cultivars. The overall iron content of the cultivars significantly diminished during storage; yet, at a low rate (T0=18.3±3.8 mg/kg; T1=17.6±4.4 mg/kg; T2=16.8±4.2 mg/kg). Analysis of variance revealed no significant differences for the protein and zinc contents of boiled tubers after different storage times.

Table 7.7: Analysis of variance for nutrient content of boiled tubers after storage (*)

Source	df	Dry matter	Energy	Protein[a]	Iron[a]	Zinc[a]
Cultivar	10	40.302 **	63.667 **	0.036 **	0.100 **	0.043 **
Time[1]	2	58.252 **	3.646	0.000	0.015 **	0.000
Cult. x time	20	2.961 *	10.324 **	0.003	0.003	0.002
Error	66	1.478	1.808	0.001	0.002	0.001
Total	98					
CV	29.79	382.11	8.52	17.59	12.27	
Mean	4.08	0.35	3.69	3.71	3.52	
R^2	0.86	0.88	0.85	0.89	0.83	

[1] = after harvest (T0), 90 days after storage (T1), 150 days after storage (T2); * $p>0.05$; ** $p>0.01$; [a] = data transformed to Log^{10}

Boiled unprocessed native-bitter cultivars and boiled white chuño

Table 7.8 presents nutrient content values for boiled unprocessed tubers and boiled white *chuño*. Without exception the gross energy content (kcal / 100g; dry weight basis) of cultivars processed in *chuño* was slightly higher than that of unprocessed tubers. On a dry weight basis, differences between the 9 cultivars concerning the gross energy content of cooked *chuño* were minimal. On a fresh weight basis, the gross energy content of cooked *chuño* ranged from 86.00 ± 5.57 kcal / 100g (*Ipillu Culebra*) to 138.67 ± 5.77 kcal / 100g (*Yuraq Siri*).

The crude protein content of all cultivars transformed into white *chuño* was considerably and significantly lower compared to unprocessed tubers. Losses of 48 up to 83% occur after freeze-drying, depending on the specific cultivar. Values of protein content in white *chuño* ranged from 1.84 up to 4.21 g / 100 g on dry weight basis (table 7.8). The cultivar *Puka Qanchillu* had the highest protein value when processed into *chuño*, both on fresh (1.15 ± 0.07 g / 100g) and dry weight basis (4.21 ± 0.13 g / 100g). The protein concentration of cooked white *chuño* from the 9 cultivars evaluated ranged from 0.49 ± 0.10 g / 100 g (*Yana Manwa*) to 1.15 ± 0.07 g / 100 g (*Puka Qanchillu*) on fresh weight basis.

The iron content of most cultivars was very similar before and after processing with the notable exceptions of *Ipillu Culebra* and *Yana Siri* (table 7.8). However, the high iron contents of these cultivars can not be considered as representative because of the disproportionally high aluminium content encountered for both cultivars; this indicates they were probably contaminated with soil residues. The iron content of boiled white *chuño* ranged from 14.62 ± 1.95 to 20.76 ± 2.57 mg / kg on a dry weight basis and 0.29 ± 0.16 to 0.65 ± 0.07 mg / 100 g on a fresh weight basis. Freeze-drying significantly reduced the zinc content of all cultivars by 69 to 85% (table 7.8). Considerable variation between the different native-bitter cultivars exists. While the zinc concentration in boiled unprocessed tuber samples ranged from 9.85 ± 0.31 to 22.52 ± 0.29 mg / kg it fluctuated between 1.79 ± 0.16 to 5.26 ± 0.75 mg / kg for boiled white *chuño* (dry weight basis).

Table 7.8: Gross energy, crude protein, iron and zinc content of boiled unprocessed tubers and boiled white *chuño* samples

Cultivar	Gross Energy (kcal / 100 g)			Crude Protein (g / 100 g)			Iron (mg / kg)			Zinc (mg / kg)		
	Boiled tubers (DWB[1])	Boiled *chuño* (DWB[1])	Boiled *chuño* (FWB[2])	Boiled tubers (DWB[1])	Boiled *chuño* (DWB[1])	Boiled *chuño* (FWB[2])	Boiled tubers (DWB[1])	Boiled *chuño* (DWB[1])	Boiled *chuño* (FWB[2])	Boiled tubers (DWB[1])	Boiled *chuño* (DWB[1])	Boiled *chuño* (FWB[2])
'Yana Manwa'	383.33 ± 1.53	394.17 ± 0.51	106.00 ± 8.19	10.73 ± 0.56	1.84 ± 0.29	0.49 ± 0.10	15.82 ± 0.54	14.62 ± 1.95	0.29 ± 0.16	11.53 ± 0.64	1.83 ± 0.32	0.04 ± 0.03
'Yuraq Lui'	384.00 ± 3.46	393.66 ± 0.43	91.33 ± 5.86	9.10 ± 0.42	2.52 ± 0.11	0.59 ± 0.03	15.72 ± 1.03	15.59 ± 2.02	0.36 ± 0.06	11.92 ± 0.59	1.79 ± 0.16	0.04 ± 0.00
'Kumpus Siri'	384.67 ± 0.58	391.88 ± 0.50	97.33 ± 4.62	11.84 ± 0.42	3.79 ± 0.33	0.95 ± 0.12	20.30 ± 0.15	20.76 ± 2.57	0.52 ± 0.04	17.00 ± 0.18	3.78 ± 0.46	0.09 ± 0.01
'Puka Qanchillu'	386.33 ± 0.58	393.47 ± 0.30	107.33 ± 7.51	8.06 ± 0.14	4.21 ± 0.13	1.15 ± 0.07	17.36 ± 0.52	15.26 ± 0.84	0.42 ± 0.01	11.63 ± 0.34	3.66 ± 0.10	0.10 ± 0.01
'Yuraq Waña'	383.67 ± 1.53	393.30 ± 0.55	120.00 ± 9.54	10.20 ± 0.08	2.93 ± 0.70	0.83 ± 0.17	16.05 ± 1.55	15.05 ± 1.59	0.46 ± 0.04	13.17 ± 0.96	3.81 ± 0.17	0.12 ± 0.01
'Yana Waña'	385.67 ± 0.58	393.46 ± 0.20	112.67 ± 2.89	9.94 ± 0.27	2.30 ± 0.15	0.66 ± 0.06	14.52 ± 0.98	15.19 ± 1.28	0.44 ± 0.04	12.08 ± 0.78	3.63 ± 0.15	0.11 ± 0.01
'Yuraq Siri'	376.33 ± 0.58	394.15 ± 0.63	138.67 ± 5.77	14.01 ± 0.62	3.21 ± 0.36	1.12 ± 0.11	21.21 ± 0.82	15.12 ± 1.39	0.52 ± 0.05	16.28 ± 0.98	2.84 ± 0.19	0.10 ± 0.01
'Yana Siri'	382.67 ± 1.15	393.23 ± 0.65	108.00 ± 6.24	10.58 ± 0.09	2.32 ± 0.13	0.63 ± 0.01	14.16 ± 0.34	23.48 ± 1.89 ¥	0.65 ± 0.07	22.52 ± 0.29	5.26 ± 0.75	0.14 ± 0.02
'Ipillu Culebra'	378.33 ± 3.51	390.17 ± 0.33	86.00 ± 5.57	11.56 ± 1.22	2.60 ± 0.14	0.57 ± 0.02	19.28 ± 0.85	34.80 ± 1.97 ¥	0.76 ± 0.09	9.85 ± 0.31	2.30 ± 0.46	0.05 ± 0.01

[1] DWB = Dry Weight Basis; [2] FWB = Fresh Weight Basis; ¥ = high values because of probable contamination of samples with soil residues as suggested by high aluminium content of *Yana Siri* (20.97 ± 3.26 mg / kg; DWB) and *Ipillu Culebra* (33.91 ± 2.88 mg / kg; DWB)

7.3.2 Dietary intake

The surveyed mothers on average were 28 years old, weighed 50.7 kg, measured 1.48 m of length, and had 3 years of formal education (21.4% were illiterate). An average of 70% of the mothers was lactating at the time the survey was conducted. The children had an average age of 20.0 months. A total of 340 children, aged between 4 and 16, participated in the measurement of the overall nutritional status at schools. One out of every four children presented global malnutrition (weight for age). Only 7.1% of the children showed normal height for age ratios, while 20.0% were severely chronically malnourished (stunted). An average of 30.3% was slightly chronically malnourished and 42.6% moderately chronically malnourished (stunted; height for age). The percentage of acute malnutrition (weight for height) was found to be minimal, in accordance with the data from INEI (2000).

Potato was a principal staple in women's diets with an average daily consumption of 839.1 and 645.4g during periods of relative abundance and scarcity respectively (table 7.9). The children's diet was also rich in potato with an average daily consumption of 202.3 g and 165.1 g during both periods of inquiry respectively. During the period of abundance the total diversity of potato cultivars consumed was higher than during the period of relative scarcity, both for women and children: 90 versus 61 cultivars for women and 81 versus 41 cultivars for children. During the period of abundance the native-floury cultivars most consumed, both in terms of quantity and frequency, were *Ajo Suytu* and *Peruanita*. The improved cultivars *Yungay* and *Canchan* were most commonly consumed during the period of scarcity.

In January and February, more than 6 months after the main harvest (*qatun tarpuy* plantings), most households have relatively few native-floury cultivars left for consumption. However, many households obtain a harvest of early producing improved cultivars from the *michka* plantings (small-scale secondary season). Therefore, potato intake was dominated by native cultivars during the period of abundance while improved cultivars were more important during the period of scarcity (table 7.9; fig. 7.1). Levels of consumption of *chuño* were exceptionally low during the period of scarcity. This was a consequence of the absence of frosts during the previous processing season (June - July 2004); this climatic abnormality had caused serve losses of potato being processed into *chuño*.

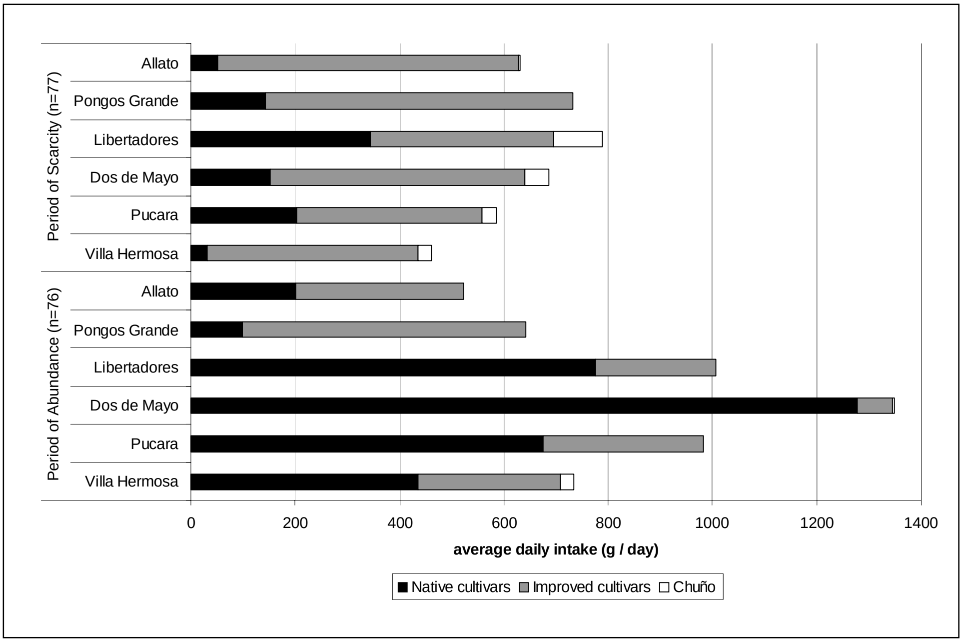
Table 7.9: Average daily potato intake (g / day) by period enquiry

Type of potato	Period of Abundance[1]		Period of Scarcity[2]	
	Women (n=76)	Children (n=75)	Women (n=77)	Children (n=78)
Native cultivars	543.64	136.29	166.79	55.91
Improved cultivars	284.18	65.65	442.25	99.15
Chuño	5.71	0.39	36.36	10.03
Total	833.54	202.33	645.40	165.09

[1] = May - June 2004; [2] January - February 2005

Considerable differences between communities exist concerning the average daily intake of potato by adult women (fig. 7.1). Intake was highest in the communities of Dos de Mayo and Libertadores during the period of abundance with an average intake of 1,348 and 1,007 g / day respectively. In the communities of Villa Hermosa, Pucara, Dos de Mayo and Libertadores the following pattern can be observed: high levels of consumption of native-floury cultivars after the main harvest (period of abundance), a considerable decrease in the average daily intake of potato during the period of scarcity, and an increased importance of improved cultivars compared to native-floury cultivars during the period of scarcity. The reality in the communities of Pongos Grande and Allato is quite different with improved cultivars dominating average daily intake during both periods of inquiry, no *chuño* consumption during the period of scarcity, and slightly increased levels of total potato intake during the period of scarcity.

Figure 7.1: Average daily potato intake by weight (g / day) for women by community and period of inquiry



Tables 7.10 and 7.11 provide an overview of the quantitative contribution of the different potato cultivar categories (native-floury, native-bitter = *chuño*, improved), potato overall and total food consumption to the average daily energy, protein, iron and zinc intake of women and children. The overall consumption of potato contributes significantly to the total intake of all nutrients. Native-floury and improved cultivars complement each other with native-floury cultivars proportionally providing most of the energy, protein, iron and zinc intake from potato during the period of abundance and improved cultivars occupying that same position during the period of scarcity.

After potato, carrots and olluco (*Ullucus tuberosus*) were the most frequently consumed root and tuber crops during the period of abundance while carrot intake alone was more frequent during the period of relative scarcity. Barley, rice, oats and pastas were the most frequently consumed cereal-based products for women and children during both periods of inquiry, while fababeans and peas were the most frequently consumed legumes for both groups and periods. Green vegetable consumption was very infrequent during both periods. Overall, women and children most frequently consumed onions and garlic. Sacha col or yuyo (*Brassica rapa*), a weedy vegetable commonly collected, was among the most frequently consumed vegetables during the period of relative scarcity. Overall, frequencies of fruit, meat, milk and egg consumption were very low for both women and children and during both periods of inquiry.

Table 7.10: Average daily energy, protein, iron and zinc intake for women by period of inquiry

Source	Period of Abundance[1]				Period of Scarcity[2]			
	Energy (kcal/day)	Protein (g/day)	Iron (mg/day)	Zinc (mg/day)	Energy (kcal/day)	Protein (g/day)	Iron (mg/day)	Zinc (mg/day)
Nat. cultivars	642	13.87	2.63	1.85	194	4.30	2.21	0.58
Imp. cultivars	283	6.13	1.42	0.63	472	10.23	0.83	1.64
Chuño	18	0.11	0.19	0.05	39	0.23	0.14	0.02
All potatoes	944	20.11	4.24	2.52	706	14.77	3.18	2.24
Total intake[a]	2155	49.72	19.11	8.47	2173	56.22	24.31	9.93

[1] = May - June 2004; [2] January - February 2005; [a] = from all food sources

Table 7.11: Average daily energy, protein, iron and zinc intake for children by period of inquiry

Source	Period of Abundance[1]				Period of Scarcity[2]			
	Energy (kcal/day)	Protein (g/day)	Iron (mg/day)	Zinc (mg/day)	Energy (kcal/day)	Protein (g/day)	Iron (mg/day)	Zinc (mg/day)
Nat. cultivars	161	3.49	0.66	0.47	65	1.41	0.28	0.20
Imp. cultivars	65	1.41	0.33	0.14	106	2.31	0.50	0.37
Chuño	1	0.01	0.01	0.00	11	0.07	0.04	0.01
All potatoes	227	4.91	1.00	0.61	183	3.79	0.82	0.57
Total intake[a]	616	14.7	5.3	2.43	684	17.9	7.1	3.43

[1] = May - June 2004; [2] January - February 2005; [a] = from all food sources

Figures 7.2 and 7.3 provide an overview of the relative contribution of different food sources to total energy, protein, iron and zinc intake of women and children. Potato provides most of the total energy intake for women (43.8%) and children (36.8%) during the period of abundance while cereals proportionally provide most energy during the period of scarcity. A similar tendency can be observed for protein intake: most protein comes from potato during the period of abundance and from cereals during the period of scarcity. Legumes, meat and dairy products also make important contributions to the total protein intake of women and children. Cereals contribute most iron and zinc for both women and children and periods of abundance and scarcity, followed in importance by potato. Iron and zinc intake from rich sources such as meat is very limited.

The overall diet of women and children as measured in this study is deficient in energy, iron and zinc while sufficient in quantity of protein (table 7.12). Potato provided between 23.0 and 38.6% of the recommended total energy requirements depending on the group (women / children) and period (abundance / scarcity) of inquiry. Potato contributes significant amounts of protein, especially for children, during both periods of inquiry. The potato only covers a small percentage of the total iron requirements of women and children. Potato generally contains high levels of ascorbic acid, which is known to enhance bioavailability of iron (Fair Weather-Tait, 1983). Therefore the contribution of potato to the overall nutritional status may in fact be more important if it is consumed together in the same meal with iron from cereals. Average potato intake contributes 22.6 and 19.6% for women and 7.5 and 7.0% for children of required zinc intake for the period of abundance and scarcity respectively. This is a small but important contribution, especially for children, considering that the overall diet is severely deficient in zinc.

Figure 7.2: Contribution of food sources to total energy, protein, iron and zinc intake of women

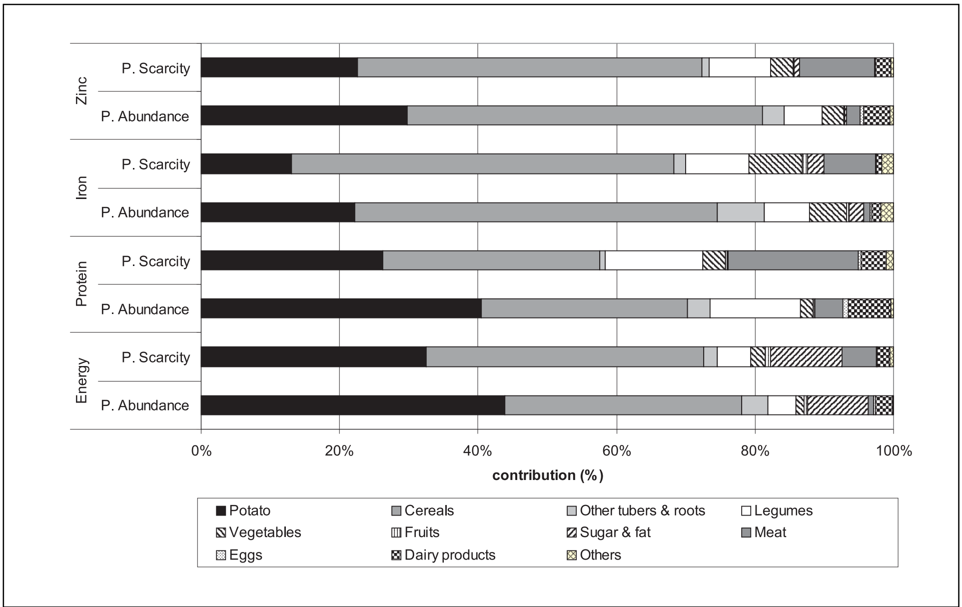


Figure 7.3: Contribution of food sources to total energy, protein, iron and zinc intake of children

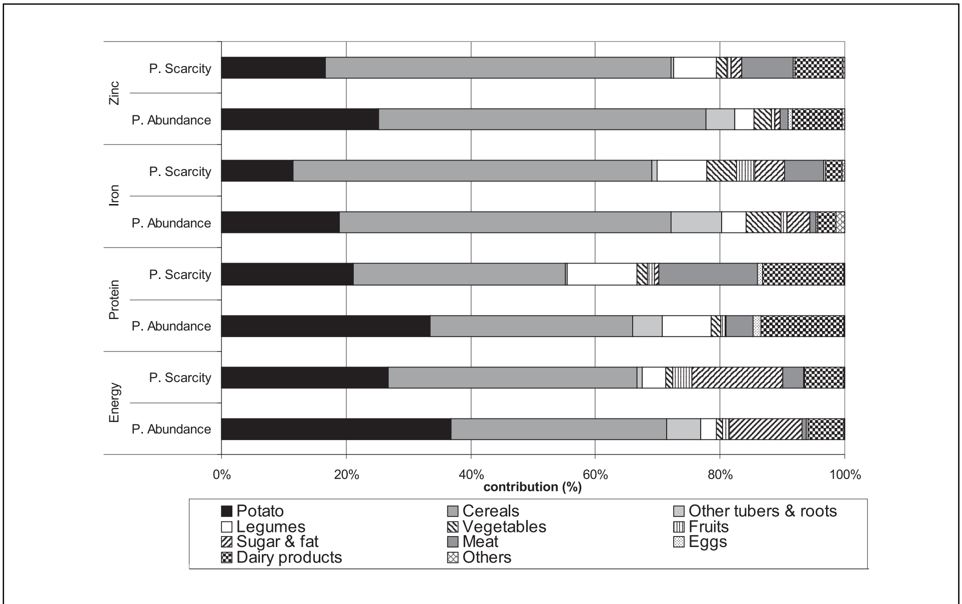


Table 7.12: Coverage of the total food and potato intake compared to recommended requirements

	Period of Abundance[1]				Period of Relative Scarcity[2]			
	Coverage by total diet (%)		Coverage by potato (%)		Coverage by total diet (%)		Coverage by potato (%)	
	Women (n=76)	Children (n=75)	Women (n=76)	Children (n=75)	Women (n=77)	Children (n=78)	Women (n=77)	Children (n=78)
Energy	88.7	84.0	38.6	29.2	87.3	85.6	28.7	23.0
Protein	96.4	183.9	38.2	57.8	104.5	193.0	28.0	43.7
Iron[a]	29.5	40.4	6.5	7.7	35.5	54.4	4.9	6.2
Zinc[a]	76.0	29.6	22.6	7.5	85.2	41.6	19.6	7.0

[1] = May - June 2004; [2] January - February 2005; [a] based on a low bioavailability scenario

7.3.3 Cultural connotations

Consumption of biodiverse potatoes

Some important differences between the potato and other foods shape the prominent role that diverse potato cultivars have within Huancavelica's food system. First, the potato is an ancestral crop and food. Numerous cultural expressions accompany the cultivation cycle of potato: special competitions for footplough-based land preparations (*yupanakuy*[6]), coca chewing next to the field before hilling, preparation of an earth oven (*pachamanka*[7]) at harvest, among others. Yet, the final goal of the potato management cycle is to have tubers available for consumption. Consumption is embedded within a larger cultural setting of production and follows processes which transform raw ingredients into particular dishes. Second, the potato is one of few staples consumed by highland farmers and is generally on the menu more than once a day. One source of variation within a seemingly monotonous diet is provided by cultivar diversity.

Processes commonly used to prepare potatoes include boiling, steaming, frying, toasting and freeze-drying. Several processes and dishes require a mix of cultivars rather than a single cultivar; it is the inherent diversity and combination of cultivars which is appreciated. Examples include the *pachamanka* (through steaming) and *chuño* (through freeze-drying) from small "leftover" tubers of mixed native-floury cultivars. Homemade *pachamanka* in Huancavelica is a dish which normally contains between 3 to 10 native-floury cultivars. Freeze-dried *chuño* of multiple native-floury cultivars is considered an exquisite type of *chuño* which is exclusively used for home consumption and rarely sold.

However, for other preparations certain "types" of potato cultivars are commonly used. Specific cultivar traits determine their use for specific processes and dishes. An example concerns cultivars used to obtain boiled potatoes for direct consumption and soups or stews. Boiled potato cultivars used for direct consumption should be floury (high dry matter content); commonly referred to in Quechua as "*machqa machqa*". Soups and stews, however, commonly contain "watery" cultivars (low dry matter content); commonly referred to as "*luqlu*" by farmers in Huancavelica.

On a very specific level, there are dishes which require particular cultivars. An example is "*saqta mati*[8]", a dish commonly served at special occasions; it should contain the cultivar with the same name (*Saqta Mati*) or cultivars belonging to the *Pasña* cultivar group (*Chiqchi Pasña*, *Puka Ñawi Pasña, Yuraq Pasña*). These particular cultivars have combinations of traits (texture,

[6] A competition between groups (two men / one woman) to prepare land for potato after prolonged fallow.
[7] A typical dish from central Peru which involved steaming ingredients (potato, oca, fababeans, etc.) in an oven made of stones and earth.
[8] A typical dish from Huancavelica: boiled potatoes with meat served on a plate made of a gourd.

taste, odor) which make them preferred for the dish. Specific cultivars are also used for certain nutritional conditions. For example, the cultivars *Yana Puqya* and *Suytu Puqya* are considered to be extra nutritious according to local tradition and recommended for pregnant women or persons recovering from sickness. Further, plant parts other than tubers of particular cultivars are also used in local cuisine. Potato leaves of the native-bitter cultivars *Yuraq Suytu Siri* and *Puka Qanchillu* are frequently used by Chopcca Indians from the communities of Dos de Mayo and Libertadores to give a taste of "*charki*" (dried meat) to soups.

While different combinations of particular cultivars to be used for distinct processes and dishes constitute one motive underlying the farmer's use of diverse cultivars, there is also an intrinsic value to diversity itself. This is exemplified by the most humble and widely appreciated dish eaten by farmers in Huancavelica: "a bowl of boiled mixed native potatoes" consumed on its own. What may seem simple to the outsider actually is a powerful symbol of both culinary delight and identity for the Quechua household. A meal of mixed cultivars (*chaqru*) is biodiversity transformed into diverse sensory perceptions: color, texture, taste and odor. During the meal each family member carefully picks a tuber satisfying long established preferences, instant curiosity and appetite for variation. The mix of diverse cooked potato cultivars is an expression of Andean diversity in the kitchen. Having the luxury of choosing from a wide array of cooked cultivars is a welcome diversification within a diet dominated by potatoes.

A characteristic component that underlies the consumption of diverse cultivars by farmers in Huancavelica relates to their combined varietal quality traits and related expressions. The repertoire of preference traits associated with varietal quality of particular cultivars is elaborate and includes texture, taste, odor, longevity in storage, among others. Not surprisingly each of these traits is associated with a special vocabulary in the Quechua language. Texture is generally the most obvious trait associated with quality by farmers: the higher the dry matter content, the better the quality. This is one of the main reasons why improved cultivars are considered to be of inferior culinary quality; because of their low dry matter content. Taste and odor are considered important by all farmers; each potato cultivar has a particular taste and smell. When asked for their "favorite" cultivar, farmers were rarely able to specify. Generally they would mention a list of cultivars and their pros and cons when consumed. Longevity in storage influences the repertoire of cultivars farmers will consume throughout the year. Some, such as the cultivars *Peruanita* and *Runtus*, only store well for 3 months and have to be consumed first. Others, such as *Ayrampu* and *Yana Puqya*, can be stored for up to 6 months and are consumed over prolonged periods. Because diverse native cultivars are generally associated with high quality they are at the same time considered particularly apt to be used to express a sense of community and appreciation. Mixed native cultivars are commonly used as a gift to reaffirm social relationships while sharing a meal of diverse cultivars is considered a special "treat" for those who share the meal.

Potato as a socioeconomic class marker

Workshops and surveys done in 7 communities to define and characterize local definitions of well-being (poor versus non-poor) revealed some insights into the local food culture, including the role of potato. Relative "well-being" as a social construct was defined at the level of each community. Community members themselves defined poor versus non-poor according their own socio-economic environment and concepts. Community profiles were uneven. Yet, in general terms, families with access to off-farm employment were rarely ranked by their own community members as being poor by local standards. The poorest households in rural communities in Huancavelica were frequently families led by single mothers, families with one or more handicapped or severely sick members, and persons of old age abandoned by their direct family. During community workshops farmers (men and women) listed locally available food items / dishes they associated with being poor or non-poor. The consumption of barley gruel and barley soup were commonly associated with being poor while the consumption of rice, pastas, eggs, meat and vegetables was commonly associated with being non-poor. Unlike other staple food crops, potato was rarely considered either a poor or rich man's crop (table 7.13). With some notable exceptions, it was commonly associated with consumption by all social strata. The consumption of *chuño* was associated with being poor in the communities of Huayta Corral, Tupac Amaru and Pongos Grande. Potato soup was also associated with being poor in the community of Pongos Grande.

Table 7.13: Food items / dishes associated with being poor versus not poor (n=256[1])

Community	Foods of the poor	Foods of the non-poor
Allato	Barley gruel, barley soup	Cheese, eggs, milk, meat
Pongos Grande	Barley soup, potato soup, *chuño*	Eggs, cheese, meat, legumes
Villa Hermosa	Barley soup, zanco (flour with pig fat)	Meat, eggs, vegetables
Pucara	Barley gruel, water from well	Rice, milk, meat, tap water
Dos de Mayo	Barley gruel, barley soup	Fababeans, meat
Libertadores	Barley soup, mashua, weedy vegetables (yuyos, berros)	Vegetables, zanco (flour with pig fat), potato, meat
Huayta Corral	Barley gruel, *chuño*	Meat, eggs, cheese, rice, pastas
Tupac Amaru	Barley gruel, *chuño*	Rice, pastas

Source: community workshops in each community; [1] = workshop participants

Poor households cultivated an average of 20 potato cultivars while non-poor households cultivated an average of 49 cultivars. So, families considered as non-poor within their communities maintain and use higher levels of infraspecific diversity. An average of 68.3% of the households classified as poor consumed only two meals a day. In 2005 poor households on average spent S./ 157.00 ($US 46.72) per month, 52.1% on food. Non-poor household's total monthly spending was higher with S./ 261.66 ($US 77.88) per month, 43.6% on food. The potato consumed by both poor and non-poor households was generally produced on-farm rather than purchased. However, some of the poor families from the communities of Dos de Mayo and Pongos Grande sold their "high-value" native-cultivars in order to purchase larger quantities of relatively "low-value" improved cultivars.

7.4 Discussion and conclusions

Potato is the indigenous mainstay within high-altitude food systems of Huancavelica, Peru. Species diversity and consequent dietary variability is key to enhanced nutrition. Results from this study suggest that *in-situ* conserved infraspecific diversity can potentially also make a valuable contribution, as specific native potato cultivars are more nutritious than others. Several of the native-floury cultivars contained higher content values for specific nutrients than those reported as representative for native potatoes, based on "yellow potato" (*S. goniocalyx*) in the Peruvian Table of Food Composition (Zavaleta *et al.*, 1996). This includes the cultivars *Runtus* and *Yana Puqya* for protein content (3.0 and 2.8 g / 100 g compared to 2.0 g / 100 g in the food table) and *Chiqchi Pasña* for iron content (0.7 mg / 100 g compared to 0.4 mg / 100 g in the food table).

Traditional storage under highland conditions does not very much affect the nutritional quality of native-floury potato cultivars, with the notable exception of iron content which diminishes at rates lower than 10% during total storage time (5 months). Traditional freeze-drying of diverse native-bitter cultivars results in a product (*chuño*) of inferior nutritional quality when compared with the nutrient content of unprocessed tubers. The energy and iron content of boiled *chuño* remains comparable to that of unprocessed boiled tubers. However, the loss of protein and zinc is considerable with losses of 48 to 83% for protein and 69 to 85% for zinc. Nevertheless, *chuño* offers advantages as it can be stored for very long periods, maintains high gross energy contents and converts tubers that are otherwise not consumable because of their high glycoalkaloid content.

The potato is sometimes accused of being a contributor rather than a solution to malnutrition. This because the potato dominates the relatively monotonous diets of rural families in the highlands and is generally considered a source of energy rather than of protein or minerals. However, the data from the dietary intake study confirms that potato is a main staple that sustains rather than inhibits quantitative and qualitative food security for rural households. The potato contributes significantly and positively to the nutritional balance and the recommended requirements for energy, protein, iron and zinc of women and children during periods of relative food abundance and scarcity. The coverage of iron and zinc requirements through potato is limited, yet important for the highland diet which is generally deficient in minerals. Other food categories, especially cereals (barley), also provide substantial contributions to the recommended requirements.

Differences between the communities concerning the role of potato within the diet are likely related to their distinct socioeconomic realties. The high daily levels of potato consumption by adult women from the communities of Dos de Mayo and Libertadores can be partially explained by their relative distance from major urban markets and the maintenance of a strong cultural identity as Quechua Indians. Farmers from both communities predominantly rely on local produce for consumption, even though some households were observed to sell small amounts of native potato cultivars to purchase larger quantities of improved cultivars. Monetary purchase of food is generally restricted to basic ingredients such as salt, sugar and cooking oil. Both communities belong to the ethnically distinct Chopcca Indians, a region where potato is an icon of the indigenous identity. The reality in the communities of Pongos Grande and Allato is quite different. Most notably because households predominantly consume improved cultivars throughout the year while *chuño* is not consumed at all. Households from Pongos Grande are renowned for the quality of the native-floury cultivars they produce and commonly sell their produce at the semi-urban Lircay market to purchase improved cultivars at lower prices. Many households from Allato have direct relatives working for regional mining companies and purchase improved cultivars on the market. Farmers from both communities do not grow native-bitter cultivars for *chuño* processing.

Native-floury and improved potato cultivars complement each other well within the food system. Each cultivar category occupies an essential role providing food at different moments in time. Diverse native-floury cultivars provide the bulk of the potato consumed in May and June during the main harvest season while improved cultivars supply fresh tubers and essential nutrients during the months of January and February when longer cycle native-floury cultivars are still growing. Surprisingly, native-bitter cultivars in the form of *chuño* were not an important food source in terms of their contribution to the average daily intake during the period of relative food scarcity. However, this was probably an atypical situation and a consequence of the absence of frost during the previous processing season (June 2004).

Malnutrition is a serious problem in the communities with 20% of the children severely chronically malnourished and 42.6% moderately chronically malnourished. Some regional food donation programs still consider protein a priority. However, contrary to common perception, malnutrition in Huancavelica is not a protein problem. It is principally a micronutrients problem, but also a problem of total energy coverage. Minerals are not contributed in sufficient quantities by the standard diet and this study shows that total food intake only accounts for 40.4 to 54.4% of the iron and 29.6 to 41.6% of the zinc recommended requirements for children. This is a direct consequence of the lack of meat, milk, egg, fruit and vegetable intake. The consumption of these products is almost negligible.

Food system interventions aimed to reduce levels of malnutrition and improve the overall nutritional situation of children and adult women in Huancavelica should be thought through thoroughly. Farmers are not passive recipients of knowledge and technology from outside. Rather, they continuously modify knowledge and practices to fit these in with tradition and new realities. Interventions by outsiders should build on this potential and involve farmers in reinventing their local food systems to make them more nutritious. There is certainly no lack of potential options to combat malnutrition. However, interventions should preferably be constructed bottom-up taking local food culture into account, build on the lessons provided by numerous previous and ongoing interventions throughout Huancavelica, and part from the concept of food sovereignty making the best possible use of local resources rather than foment long-term dependency on outside aid.

Education about nutritional needs is one important component that can help farmers modify cropping systems and diets to include more nutritious foods. A range of interventions can be considered, including the use of nutritious native Andean crops such as quinoa (*Chenopodium quinoa*), maca (*Lepidium meyenii*) or tarwi (*Lupinus mutabilis*), the promotion of small livestock such as guinea pigs, rabbits and chickens, the introduction of greenhouses and vegetable cropping, food supplementation for the most vulnerable population (children), among other options. The challenge is to work with farmers on a diverse range of options and develop robust local food systems that not only provide more nutritious food but do so in a culturally appropriate way that strengthens the ecological and genetic diversity that characterizes the Andes.

The consumption of diverse potato cultivars is entangled with cultural constructions of meals and local perceptions of preference traits and quality. How Andean farmers consume potatoes is comparable to how the France consume cheese or the Italians pasta. The potato is historically embedded into the region's food culture. Households in Huancavelica consume numerous potato cultivars rather than a single cultivar because different dishes either require a mix of cultivars or some specific cultivars. Further, cultivar diversity itself is an established and appreciated diversification within a diet dominated by potatoes. Indeed, a large repertoire of combined preference traits associated with varietal quality is offered by a pool of cultivars rather than a single genotype.

The potato itself, as a food item and species, is neither considered a crop of the poor nor of the rich. Potato is eaten by everybody and as such, at least at the surface, not an obvious class marker. However, at a deeper level certain dishes or products and the overall cultivar diversity grown and used by a household do mark regional perceptions of relative wealth. Potato soup or *chuño* can, in specific contexts, be considered as food of the poor. This is likely related to the fact that soups are generally not rich in potato, but serve to "fill the stomach". Freeze-dried *chuño* is generally available when few other foodstuffs are in store and therefore commonly consumed by those who have few options to acquire anything else during periods of hardship. Interestingly, the research shows that households locally recognized as non-poor grow and use more than twice the amount of potato cultivars compared to their poor counterparts from the same communities. This suggests that the use of a large number of cultivars (49 on average) is a "luxury" of households that are "better off". Nevertheless, households locally considered poor still maintain and use an appreciable number of cultivars (20 on average).

8 Conclusions: implications for externally driven R&D-oriented *in-situ* conservation and areas of future research

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This chapter highlights the main conclusions and provides answers to the research questions posed in chapter 1 of this thesis. It does so by taking the different system levels explored throughout the thesis into account: from alleles, cultivars, and botanical species up to their placement within the landscape, as well as the overarching links to seed and food systems. The dimensions of time and space are inferred upon by discussing change processes within the Andean environment and their drivers. The chapter also reflects upon implications for externally driven R&D-oriented *in-situ* conservation efforts which seek to support dynamic and ongoing farmer-driven conservation. Further, selected priority areas of future research are identified and, where appropriate, links to other parts of the Andes are drawn.

8.1 Conservation of species and cultivars

8.1.1 Species, cultivar and allelic diversity

This study shows that farmers maintain all the cultivated potato species previously reported for Huancavelica (Ochoa, 2003), except *Solanum phureja*. The latter seems to have been subject to regional species loss. Collectively farmers maintain at least 557 morphologically and 406 genetically unique native cultivars belonging to *S. goniocalyx*, *S. stenotomum*, *S. chaucha*, *S. juzepczukii*, *S. tuberosum* subsp. *andigena* and *S. curtilobum*, thus confirming the region's importance as a "hotspot" of both species and cultivar diversity. All species, with the exception of the bitter *S. juzepczukii* and *S. curtilobum*, were encountered in each of the eight research communities. The bitter cultivated species were not encountered in the communities of Pongos Grande and Allato where freeze-dried *chuño* is generally not consumed. This confirms the importance of use rationales for farmer-driven *in-situ* conservation (chapter 7).

Overall regional allelic diversity is well represented and preserved at the level of locally-recognized individual farmer families, independently whether the farmer family maintains medium or large-size cultivar stocks (chapter 2). However, cultivars are arguably the basic conservation unit for *in-situ* conservation, both for farmer and externally driven efforts, as they are the tangible folk taxonomic entity farmers recognize (chapter 3), have an intrinsic value on their own as unique genotypes which are historically and culturally used by Andean communities, and are easier to characterize under field conditions as compared to their inherent allelic diversity. Farmer family cultivar stocks in particular communities tend to be much more diverse than in others (chapters 2 and 4). This has implications for externally driven R&D-oriented *in-situ* conservation projects in the sense that targeting becomes increasingly important. While the selection of communities will depend on the total size of a community's cultivar pool in combination with the number of families maintaining diverse cultivar stocks, the prioritization of genotypes and inherent allele diversity will ideally depend on their relative abundance.

8.1.2 Genetic erosion and changing cultivar pools

Considerable overlap exists among the alleles present in the contemporary regional *in-situ* collection maintained by farmers in Huancavelica and CIP's geographically restricted core *ex-situ* collection from central Peru. This contradicts the common notion that genetic erosion of potato in the Andes is severe and widespread (e.g. Fowler and Mooney, 1990; Ochoa, 1975). However, an underexplored difference between the central-southern and northern Andes seems to exist. In the northern Andes, particularly in Ecuador, cultivar loss and consequent genetic erosion of potato is frequently reported (Forbes, pers. comm.; Monteros, pers. comm.; Weismantel, 1988). Therefore, in order to provide real evidence of possible genetic erosion, future research should ideally prioritize the structural comparison of *in-situ* versus *ex-situ* cultivar and molecular diversity in regions where diversity is known to have existed in the past and where genetic erosion is considered a threat. At the same time, if genetic erosion is detected, it will be important to identify the underlying processes. It also seems worthwhile that future research looks deeper into the specific factors underlying apparent species loss of *S. phureja*. Loss of this particular species has also been reported in other parts of the Peruvian Andes (Salas, pers. comm.; Zimmerer, 1991a, 1992). *S. phureja*'s distinct features, such as its traditional cultivation in areas below 3,400 m and short tuber dormancy, may be related to its rapid loss.

This study also shows that farmers grow numerous cultivars which are not necessarily present in CIP's *ex-situ* collections. Unique potato cultivars or genotypes shaped by particular allele combinations abound in Huancavelica (chapter 2). Though some of these cultivars may be cosmopolitan and thus covered within CIP's *ex-situ* collection by accessions of a geographical origin other than central Peru, the contemporary overall structure of the regional cultivar pool also suggests that farmer-driven *in-situ* conservation is dynamic and likely subject to cultivar turnover through seed flows, evolution via gene flows or mutations. The actual processes driving temporal change within regional cultivar pools are still little understood and represent an exciting area of future research. It will be valuable to obtain a better understanding of the relative contribution of long-term cultivar turnover and evolutionary processes on the temporal dynamics and changing composition of regional cultivar pools. Little real evidence exists for ongoing crop evolution under *in-situ* scenarios, even though the evolutionary process is often considered to represent a main added-value of on-farm conservation.

8.1.3 Future documentation

The high levels of infraspecific diversity maintained in the department of Huancavelica are comparable to other parts of the central-southern Peruvian and Bolivian Andes where farmers are also known to conserve hundreds of native cultivars (see Cosio Cuentas, 2006; Hancco *et al.*, 2008; Pérez Baca, 1996; Terrazas and Cadima, 2008; Ugarte and Iriarte, 2000; Zimmerer, 1996). Much of the management of these geographically distanced cultivar pools takes place under comparable conditions at high altitude following a single predominant annual cropping calendar with mixtures (*chaqru*) being grown in scattered fields by indigenous farmers. However, beyond these generalities, little is known about the molecular and morphological relatedness (uniqueness versus overlap) of cultivar populations by department. A clear need exists to develop a detailed baseline study of the contemporary spatial distribution of alleles and cultivars throughout the Andes so that the crop conservation community knows what is present in the field and how cultivar populations maintained by farmers in different highland regions relate to each other. A structural inventory at such a scale would have to be done applying uniform procedures for characterization so that datasets are comparable. Expected outcomes would include catalogues, databases, detailed geographical distribution maps and knowledge of relative cultivar and allele abundance including endemism[1] .

8.2 Interface between farmer and formal classification

8.2.1 Folk and formal taxonomy

Folk taxonomy of Andean potatoes in Huancavelica recognizes at least 5 ranks and numerous taxa. A reasonable, albeit imperfect, overlap exists between folk taxonomy (folk specific and varietal taxa) and formal systems of characterization based on morphological descriptor lists and microsatellite markers (chapter 3). While formal taxonomy is predominantly concerned with botanical species, folk taxonomy of the cultivated potato typically focuses on infraspecific diversity with large numbers of taxa being recognized by farmers at the folk specific and varietal level. This implies that folk taxonomy of the cultivated potato can in principle be considered an appropriate system to obtain an overall impression of the richness of those conservation units of interest for *in-situ* conservation (cultivar groups and cultivars). Nevertheless, formal tools of characterization should also be adopted by R&D-oriented *in-situ* conservation projects as naming practices within and among Andean communities are generally not coherent for uncommon genotypes of priority interest for conservation efforts.

8.2.2 Folk descriptors and nomenclature

This study shows that farmers are well able to classify their cultivar stocks without exposing tubers through the use of 22 plant descriptors (above-ground plant parts). Additionally, farmers use 15 folk descriptors for tubers. Future research could try to build on this indigenous knowledge system and validate the additional use of selected folk descriptors for the formal characterization of infraspecific diversity. The nomenclatural system of cultivar naming is guided by a consistent logic with primary cultivar names (nouns) generally referring to a folk specific taxon through predominant metaphorical reference to tuber shape and secondary cultivar names (adjectives) predominantly providing direct reference to tuber color. This basic linguistic principle of the potato's indigenous biosystematics as confirmed in this study (chapter 3), particularly at the increasingly exclusive levels of folk specific and varietal ranks, also underlies farmer classification in other regions. This becomes apparent when one observes regional lists of cultivar names (e.g. Cosio Cuentas, 2006; Soukup, 1939; Terrazas and Cadima, 2008).

[1] Ornithologists set particularly high standards for baseline knowledge about the *in-situ* distribution of bird species, including knowledge about their distribution, endemism and vulnerability (see Schulenberg *et al.*, 2007). Obtaining a comparable level of knowledge for native potato cultivars poses an ambitious but necessary target for crop conservationists.

8.3 Annual spatial patterns of conservation

8.3.1 Time: cropping and labor calendars

Contemporary annual spatial management of potato infraspecific diversity in Huancavelica is characterized by the existence of one predominant cropping season, field scattering practices, and generally versatile cultivars being environmentally managed for their combined resistance traits rather than habitat restrictiveness. Two complementary potato cropping calendars exist (chapter 4); however, farmers predominantly rely on a single annual cropping season and about the only flexibility built into the calendar of the so-called "big planting" (*qatun tarpuy*) relates to the spread of labor peaks through the use of different footplough-based tillage systems. Even though the main cropping season lasts for 6 months, farmers have limited flexibility concerning the temporal management of native potato cultivars: most have long growing cycles (150-180 days) and their cultivation is generally rain-fed. Dependence on a single predominant cropping season, even with spatial risk management through field scattering, means that farmers are relatively vulnerable to biotic and abiotic stress which can potentially lead to severe production losses (chapter 7). With increased worldwide interest in zero and minimal tillage systems for conservation agriculture and few technologies available for the cultivation of potato under such management schemes, it seems worthwhile for future research to look deeper into the benefits and adaptive potential of Andean tillage systems beyond labor distribution, including the quantification of their ability to prevent erosion, build-up soil organic matter and store carbon.

8.3.2 Space: the cropping environment

Native-floury, native-bitter and improved potato cultivars, each represented by a different set of cultivated potato species, show considerable overlap concerning their altitudinal distribution patterns. The notion that these cultivar categories occupy separate production spaces (so-called "altitudinal belts") is rejected as results show that differences between the altitudinal medians for areal distribution of the categories by altitude are modest (chapter 4). Annual field scattering practices resulting in households planting numerous spatially dispersed potato fields is a consequence of combined rationales, including differential management of cultivar categories (native-floury, native-bitter, improved), overall risk avoidance, and inheritance regimes fomenting land fragmentation. Depending on the community, households annually crop an average of 3.2 to 9.1 potato fields measuring between 660 to 1,576 m^2 and containing up to a hundred cultivars per field. This study shows that most native cultivars are versatile (chapter 4), producing well in several altitude-differentiated agroecologies rather than being adapted and restricted to a narrow microhabitat. Neither the management of high levels of diversity managed by farmers nor field scattering is a direct consequence of niche adaptation. Rather, it is suggested that farmers conduct annual spatial management by deploying combined tolerance and resistance traits imbedded in particular cultivar combinations (single cultivar stands or mixtures) in order to confront the predominant biotic and abiotic stresses likely to be present in different agroecologies. Andean farmers manage GxE adaptation for overall yield stability rather than fine-grained environmental adaptation of native cultivars. Future research could try to provide more evidence for this apparent logic through research on the effect of specific biotic and abiotic stresses on complete cultivar mixtures (*chaqru* stands) compared to counterfactual single cultivar stands. Similar research has been suggested and done for late blight (*Phytophthora infestans*) involving relatively few potato species and cultivars representing host diversity (Finckh *et al.*, 2007; Garrett and Mundt, 2000; Garrett *et al.*, 2001; Phillips *et al.*, 2005). The effect of traditional cultivar mixtures and their possible inherent resilience to confront stresses, such as Andean weevil (*Premnotrypes* spp.), frost, hail or drought, have been little investigated.

8.3.3 Adapting to a changing environment

Climate change in the Andes is expected to increase the levels of stress from drought, frost, hail, pests and diseases (Barclay, 2008; Bradley *et al.*, 2006; Hijmans, 2003; Vuille *et al.*, 2003). Therefore it is important that externally driven *in-situ* conservation efforts support farmers to counteract possible negative impacts. Adapted temporal and spatial management will become increasingly important for highland farmers and while new technologies such a small water-harvesting schemes may increase farmer's flexibility (out-off-season cultivation, expanded secondary season: *michka*), it is also probable that adaptation mechanisms may be imbedded within farmers' own diverse cultivar pools where traits such as earliness, drought resistance and frost tolerance are likely to be present. The potential use of *in-situ* conserved genetic diversity towards climate change adaptation and consequent temporal and spatial shifts in cropping patterns pose necessary and challenging areas of future research.

8.4 Land use and conservation

8.4.1 Tendencies

Growth of the potato cropping area in Huancavelica between 1995 and 2005 is spearheaded by improved cultivars and possible because of reduced fallow periods on existing land in combination with the expansion of the agricultural frontier toward pasture lands at ever higher altitudes. This study shows that areal growth is particularly fast between 3,900 and 4,350 m and that fallow periods at these extreme altitudes are relatively long compared to fallow of fields at lower altitudes (chapter 5). Land use tendencies show there is no evidence for a straightforward replacement of one cultivar category by another resulting in the replacement of infraspecific diversity. The cropping area dedicated to genetically diverse cultivar mixtures (*chaqru*) tended to be more or less stable between 1995 and 2005 with a maximum decrease of 23% (2002) and increase of 31% (2005) compared the average area over the 11-year period. Ongoing and future research on *in-situ* conservation of Andean crop genetic resources should ideally continue to consistently monitor the spatial (re)arrangements of both wild and cultivated species and cultivars in order to obtain a better understanding of how climate change, human population pressure, intensified land-use and other factors will potentially affect the patterning of genetic diversity within changing agricultural landscapes.

8.4.2. Rotations

Traditional sectoral fallow systems containing high levels of infraspecific diversity have, with few exceptions, largely disintegrated and disappeared in Huancavelica between 1975 and 2005. This reflects a common trend throughout the southern Peruvian Andes (see Mayer, 2002; Orlove and Godoy, 1986; Zimmerer, 2002). Nowadays, the spatial patterning of potato genetic diversity within the agricultural landscape is increasingly characterized by patchy distribution patterns. This tendency, in combination with increased land-use intensity or decreased fallowing rates, is likely to add to higher pest and disease incidences and reduced soil fertility which, in turn, may increase the overall pressure on infraspecific diversity. R&D-oriented *in-situ* conservation efforts can potentially support diversity-rich farmers through the participatory evaluation and dissemination of technological options for integrated pest, disease and fertility management of potato so that intensification can occur sustainably. At the same time, with increased pressure on permanent highland pastures to be incorporated as new and relatively fertile agricultural land and with livestock populations likely to remain constant, there is a need for the R&D community to explore how the predominant potato - grain based rotation designs can be made more efficient through inclusion of cultivated pastures and possibly even nitrogen fixing legumes. Studying the potential of replicating community-based innovations which allow sectoral fallow systems to survive successfully and adapt to the need for more individualistic intensified household-based cropping schemes may eventually result beneficial for communities struggling to maintain common field agriculture.

8.5 Farmer seed systems

8.5.1 Storage

The separate storage of improved, native-floury and native-bitter cultivars within farmer seed stores is a consequence of the different crop management requirements these cultivar categories have. The storage of different seed lots also reflects the overall structure of infraspecific diversity and the direct links between seed lots versus field plots with physically separated lots of native-floury cultivars, including complete cultivar mixtures (*chaqru*), being particularly abundant in potato seed stores in Huancavelica. Sampling of farmer seed stores can provide adequate preliminary insight into the levels of infraspecific diversity farmers maintain and the relative abundance of particular cultivars.

8.5.2 Seed health

Understanding and monitoring the seed health bottlenecks of farmer seed systems is essential so that integrated seed management interventions can be intelligently targeted. Seed health of farmer conserved cultivar stocks in Huancavelica is affected by *Diabrotica* leaf beetle and contact transmitted viruses (APMoV, PVX) while aphid and powdery scab transmitted viruses (PMTV, PLRV, PVY) are of limited importance. Externally driven R&D-oriented *in-situ* conservation efforts should ideally enhance the capacity of biodiversity rich farmers to improve potato seed health for APMoV and PVX through simple practices such as positive selection and roguing. There are several interesting and relevant research areas of farmers' seed health management in the Andes which merit closer attention, including seed degeneration studies with native cultivars at different altitudes in order to determine the effect of the environment and climate change on rates of degeneration or even environmentally induced clean-up through natural "thermotherapy".

8.5.3 Seed procurement

Different cultivar categories and specific cultivars are procured through distinct strategies and mechanisms with both monetary and non-monetary exchange between farmers and at regular markets playing an important role in Huancavelica. During normal years without extreme events seed exchange of native-floury cultivars is practiced by few households and characterized by a limited number of transactions involving small quantities of seed of few cultivars covering relatively short distances. Native-bitter and uncommon native-floury cultivars are rarely exchanged and generally reproduced year after year by the same households that maintain them. With a comparatively high percentage of households dedicated to provision rather than acquisition and average volumes provided being higher than those acquired, high-altitude diversity-rich communities tend to be net seed exporters. Regular markets typically provide relatively large volumes of seed of a few common native-floury and improved cultivars rather than high levels of infraspecific diversity. Biodiversity seed fairs have the potential to provide small volumes of highly diverse uncommon cultivars, but competition often impedes exchange. There is a clear need for externally driven *in-situ* conservation efforts to rethink the organization of biodiversity seed fairs so that they provide real incentives for biodiverse seed exchange.

8.5.4 Seed system resilience

The farmer seed system's resilience and capacity to annually widely supply and distribute infraspecific diversity and respond to acute regional seed stress is limited. The farmer seed system can partially respond to seed stress with seed being provided through regular markets, agricultural fairs, payment in kind and farmer-to-farmer exchange, but if seed shortages are regional and severe the farmer seed system is not likely to be able to fulfill total demand. The same is true for government-organized seed donations which can become an important seed source during periods of severe seed stress. Even though donations are important in terms of volume, they are not necessarily able to cover total demand. Complete recovery of seed volumes and cultivar portfolios after a severe regional shock under the current farmer seed system scenario is likely to take several years and continued shocks may indeed impede the farmer seed system to fully recover. With severe shocks likely to become more frequent in the light of climate change it is important that future research continues to monitor regional cultivar portfolios. So-called repatriation of *ex-situ* conserved native germplasm of identical geographical origin can provide an adequate backup to the farmer's seed system after severe regional shocks. Such interventions can effectively link *ex-situ* and *in-situ* conservation, components of formal seed systems (e.g. in-vitro multiplication) and farmer seed systems (e.g. in-field multiplication), and simultaneously stimulate active links between researchers, development agents and farmers.

8.5.5 Linking formal and farmer seed systems

Farmer seed systems determine the temporal and spatial patterning of genetic variability from one season to the next. They are vital for the reproduction of the high levels of infraspecific diversity maintained by farmers in Huancavelica and throughout the central-southern Peruvian Andes. Current seed regulations in Peru impede native cultivars from entering more formalized seed system schemes, even though it is well established that both so-called formal and farmer seed systems have their strengths and weaknesses (e.g. Thiele, 1999). There is a need to start a policy debate and design adequate adapted regulations which strengthen rather than impede linkages between farmers' and formal seed systems. Farmer seed systems represent the dominant functioning model in the Andes and should ideally be strengthened through informed interventions targeting their selected weaknesses (e.g. elements of seed health and provision identified by this study). Additionally, stimulating the production and provision of Quality Declared Seed (QDS; FAO, 2006) of diverse and uncommon cultivars may be a viable scheme of linking formal and farmer seed systems with the potential to ultimately increase the household income of biodiversity-rich farmers.

8.6 Food systems

8.6.1 Nutritional composition

Genetic diversity is also expressed in nutritional variability of native cultivar pools and this study shows that some native-floury cultivars contain higher levels of protein and minerals than others. Selected native-floury cultivars even contain higher content values for specific nutrients (protein, iron) as compared to common reference values (chapter 7; Zavaleta *et al.*, 1996). The human intake of complementary combinations, such as cultivars rich in iron together with cultivars rich in vitamin C, can possibly enhance bioavailabity. Native-bitter cultivars lose nutritional value when processed into *chuño*; particularly the protein and zinc content is negatively affected by traditional freeze-drying (chapter 7; Burgos *et al.*, *forthcoming*). However, *chuño* can be stored for long periods while maintaining high levels of gross energy and thus potentially be a vital food source during times of overall food scarcity.

8.6.2 Dietary intake and nutrition

Research on dietary intake in Huancavelica shows that the potato contributes positively to the recommended requirements for energy, protein and minerals of women and children during periods of food abundance and scarcity. Interestingly, improved and native-floury cultivars complement each other as each category provides the bulk of potatoes consumed at different moments in time: native-floury cultivars during periods of relative food abundance and early-producing improved cultivars during periods of relative food scarcity. The highland diet is heavily dependent on staple foods, particularly potato and barley, and generally short in vegetable, fruit, meat and milk intake. Malnutrition in Huancavelica is primarily a consequence of micronutrient deficiency and secondarily of insufficient total energy coverage. Potential food system interventions aimed at enhancing the quality of the highland diet and reducing malnutrition should ideally strengthen local food sovereignty making the best possible use of locally available resources rather than create dependency on outside aid. Development efforts have a considerable array of potential options available, including promoting nutritious underexploited native Andean crops, rearing small livestock and practicing horticulture in greenhouses, but most importantly they should actively involve farmers, particularly women, in enhancing local food systems.

8.6.3 Cultural connotations

The potato is historically imbedded into Andean food culture. As a food item and species it is not a strong class marker as both the poor and the rich in Huancavelica commonly consume potato. However, certain dishes or products and the overall cultivar diversity used by a household do mark regional perceptions of relative wealth. The consumption of diverse rather than single native cultivars is entangled with cultural constructions of meals and local perceptions of preference traits and quality. It also represents much appreciated dietary variability within the highland diet and likely enhances the overall quality of the diet.

8.6.4 Linking nutrition and biodiversity

Future research on food systems and nutrition could build on the high levels of infraspecific diversity present in Huancavelica. Screening of native germplasm for micronutrient content can be useful for crop improvement efforts which seek to enhance the nutritional value of advanced breeding stocks (see Bonierbale *et al.*, 2007; Burgos *et al.*, 2007). Food intake studies in the Andes applying direct weighing or 24-hour recall should try to take poverty indicators into account when designing the methodology so that linkages can be drawn between the poverty versus nutritional status of the population. In general, links between *in-situ* conserved infraspecific diversity and food systems merit more scientific research emphasizing both cultural and nutritional dimensions. Externally driven R&D-oriented *in-situ* conservation efforts could try and strengthen linkages between on-farm conservation and public health services by putting biodiversity on the map of the formal health system and try and integrate local production system components and knowledge with food-based health interventions.

8.7 Towards effective R&D-oriented conservation

8.7.1 From policy commitment to practice

Farmer-driven *in-situ* conservation is a dynamic ongoing process and the outcome of diverse livelihood rationales of Andean farmers. Interest and efforts to support the process through externally driven R&D-oriented strategies is a relatively recent phenomenon. Global interest in supporting *in-situ* conservation increased after the Convention on Biological Diversity (CBD) recognized continued on-farm maintenance of traditional cultivars as a critical component of sustainable agricultural development. Equally, the more recent International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) also recognizes the importance of supporting the efforts of farmers and indigenous communities in the conservation and sustainable use of crop genetic resources. However, the science and practice of R&D-oriented *in-situ* conservation lag behind the policy commitments to its implementation. Adequate and sustainable support for *in-situ* conservation will require a concerted R&D framework, tested conservation practices and methods, as well as strategies for systematizing and disseminating replicable experiences and tools within centers of crop diversity and across agroecosystems.

Although "traditional" crop management has never been static, current rapid cultural, environmental and economic changes are also accelerating changes in farmers' livelihoods and influencing how or whether they cultivate diverse crops. There is a challenge to strengthen bridges between scientific research, development interventions and farmer's needs to sustain dynamic *in-situ* conservation. However, the objectives of the research, development and farmer communities may not necessarily coincide and complementarities and their use for pro-poor impact have yet to be fully realized while synergies and potential conflicts between farmer-driven and R&D-oriented *in-situ* conservation of crop genetic resources need to be critically explored. Ultimately, *in-situ* conservation of crop genetic resources is done by farmers and therefore R&D interventions should be participatory and seriously take farmer rationales and needs into account.

8.7.2 Learning from diverse grassroots experiences

The theoretical, conceptual and developmental framework of R&D-oriented *in-situ* conservation has evolved significantly during the last decade (e.g. Bellon, 2004; Brush, 2004; CIP-UPWARD, 2003, Maxted *et al.*, 2002), but there are still many "unknowns" as to how interventions actually materialize at ground level. During the last decade numerous conceptually different R&D-oriented *in-situ* conservation projects have been implemented throughout the Peruvian Andes (e.g. De Haan, 2002; Huamán, 2002; Suri, 2005; UNDP-GEF, 2001). Conceptually, interventions range from cultural reaffirmation strategies to market-based approaches (see Grillo *et al.*, 1994; Ishizawa, 2003; Ordinola *et al.*, 2007). Between the extremes of these different paradigms, R&D-oriented *in-situ* conservation at the grassroots level has been characterized by a mosaic of approaches ranging from seed systems interventions (seed fairs, communal seed banks, repatriation), linkages to tourism (biocultural heritage sites, potato park), capacity building (integrated crop management, curriculum building for primary and secondary education), strengthening use options (nutrition courses, food fairs), among others. Future research should prioritize the exploration of impact pathways and provide evidence of impact. How can interventions allow for continued dynamic change and evolution of farmer maintained infraspecific diversity, yet prevent genetic erosions and cultivar loss due to the livelihood shifts in rural populations? What are the impacts of the existing efforts and approaches on infraspecific diversity and farmer livelihoods? Which approaches do work? Institutional learning from the diverse interventions already implemented throughout the Andes and the diffusion of key lessons is essential for the success of new projects.

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Abbreviations

Adg	=	*Solanum tuberosum* subsp. *andigena*
AMMI	=	Additive Main Effects and Multiplicative Interaction
AMOVA	=	Analysis of Molecular Variance
ANOVA	=	Analysis of Variance
AOAC	=	Association of Official Analytical Chemists
APMoV	=	Andean Potato Mottle Virus
ARG	=	Argentina
ARTC's	=	Andean Root and Tuber Crops
Av.	=	Average
BA	=	Barley (*Hordeum vulgare*)
BOL	=	Bolivia
CBD	=	Convention on Biological Diversity
Cha	=	*Solanum chaucha*
CIP	=	International Potato Center (headquarters in Lima, Peru)
CIRAD	=	*Centre de Coopération Internationale en Recherche Agronomique pour le Développement* (Montpellier, France)
CK	=	Collective Knowledge
Coeff.	=	Coefficient
COL	=	Colombia
Cor. coeff.	=	Correlation coefficient
Cur	=	*Solanum curtilobum*
CVR	=	*Comisión de la Verdad y Reconciliación*
Cvs	=	Cultivars
DIST	=	Average taxonomic distance coefficient
DNA	=	Deoxyribonucleic Acid
DWB	=	Dry Weight Basis
ECU	=	Ecuador
ELISA	=	Enzyme-Linked Immunosorbent Assay
Ex-situ	=	Off-site (literally)
F	=	Fallow
Fam.	=	Family
FAO	=	Food and Agriculture Organization of the United Nations
FB	=	Fababeans (*Vicia faba*)
FL	=	Free Listing
F.R.	=	Fallowing Rate
FTE	=	Full-Time-Equivalent
FWB	=	Fresh Weight Basis
GECI	=	Germplasm Enhancement and Crop Improvement
GEF	=	Global Environmental Fund
GIS	=	Geographical Information Systems
GO	=	Governmental Organization
Gon	=	*Solanum goniocalyx*
GxE	=	Genotype by Environment
HCVA	=	Huancavelica
IC	=	Improved cultivars (potato)

ICBN	=	International Code of Botanical Nomenclature
ICM	=	Integrated Crop Management
ICNCP	=	International Code of Nomenclature for Cultivated Plants
ID	=	Identity
IDAHO	=	University of Idaho
IIN	=	*Instituto de Investigación Nutricional*
IK	=	Indigenous Knowledge
IL	=	Indicated Listing
INEI	=	*Instituto Nacional de Estadística e Informática*
INIA	=	*Instituto Nacional de Innovación Agraria*
In-situ	=	On-site (literally)
IPCA	=	Interaction Principal Component Axis
ITPGRFA	=	International Treaty on Plant Genetic Resources for Food and Agriculture
Juz	=	*Solanum juzepczukii*
ISC	=	*In-Situ* Collection
MA	=	Maca (*Lepidium meyenii*)
Masl	=	Meters above sea level
Max.	=	Maximum
Med.	=	Medium
MEF	=	*Ministerio de Economía y Finanzas*
Min.	=	Minimum
MINAG	=	*Ministerio de Agricultura*
n.a.	=	not applicable
NBC	=	Native-bitter cultivars (potato)
NFC	=	Native-floury cultivars (potato)
NGO	=	Non Governmental Organization
NJ	=	Neighbor Joining (clustering method)
NP	=	Native potatoes
OA	=	Oats (*Avena sativa*)
OIA	=	*Oficina de Información Agraria*
PCA	=	Principal Component Analysis
Perc.	=	Percentage
Pers. comm.	=	Personal communication
Pers. obs.	=	Personal observation
PIC	=	Polymorphism Index Content
PLRV	=	Potato Leafroll Virus
PMTV	=	Potato Mop-Top Virus
PVY	=	Potato Virus Y
PVX	=	Potato Virus X
QDL	=	Quality Declared Seed
R	=	Correlation coefficient
R&D	=	Research & Development
R.H.	=	Relative Humidity
SAHN	=	Sequential Agglomerative Hierarchal Nested
SAIS	=	*Sociedad Agraria de Interés Social*
SCRI	=	Scottish Crop Research Institute (Dundee, Scotland, UK)
SD	=	Standard Deviation
SENASA	=	*Servicio Nacional de Sanidad Agraria*
Sig.	=	Significance
SSR	=	Single Sequence Repeats (microsatellite marker)
Stn	=	*Solanum stenotomum*
Subsp.	=	Subspecies
T	=	Temperature
TA	=	Tarwi (*Lupinus mutabilis*)
Tbr	=	*Solanum tuberosum* subsp. *tuberosum*

TEK	=	Traditional Environmental Knowledge
TIGR	=	The Institute of Genomic Research
Treat.	=	Treatment
UNALM	=	*Universidad Nacional Agraria La Molina* (Lima, Peru)
UN	=	United Nations
UNDP	=	United Nations Development Programme
UNCP	=	*Universidad Nacional del Centro de Perú* (Huancayo, Junín, Peru)
Undet.	=	Undetermined
UPGMA	=	Unweighted Pair Group Method Arithmetic Average
USA	=	United States of America
VEN	=	Venezuela
WHO	=	World Health Organization

Glossary

Acero Suytu	cultivar name (potato)
Achka tulluyuq	abundant stems (Quechua)
Acobamba	province (department of Huancavelica)
Acraquia	district (province of Tayacaja)
Ahuachucha	old cultivar name (potato; Bertonio, 1612)
Ahuaycha	district (province of Tayacaja)
Aisha	see *Laymi(s)* (denomination Yauyos, Lima, Peru)
Ajo Suytu	cultivar name (potato; Cha)
Akshu	potato (Quechua; Chichaysuyo dialect; mainly department of Junín, Peru)
Alpuntu	potato berry (Quechua)
Allato	research community (this thesis)
Allca Hamacorani	old cultivar name (potato; Bertonio, 1612)
Allca Phiñu	old cultivar name (potato; Bertonio, 1612)
Allqa	two-colored (Quechua)
Allqa Ipillu	cultivar name (potato)
Allqa Palta	cultivar name (potato; Adg), literally "two-colored flat"
Allqa Pasña	cultivar name (potato; Gon), literally "two-colored girl"
Amajaa	old cultivar name (potato; Bertonio, 1612)
Amarilis	cultivar name (potato; Tbr)
Amaru Suytu	cultivar name (potato), literally "long snake"
Amqa	potato (Aymara; local Aymara dialects)
Angaraes	province (department of Huancavelica)
Ankapa Sillun	cultivar name (potato; Adg), literally "hawks nail"
Apichu	sweetpotato (*Ipomoea batatas*; old Quechua); old cultivar name (potato; Bertonio, 1612)
Araq Papa	semi-wild / consumed potato (Quechua)
Araq Peruanita	folk varietal (semi-wild / consumed potato)
Arariwas	see *Varayoqs*
Asya tulluyuq	few stems (Quechua)
Atoq Papa	wild / non-consumable potato (Quechua), literally "fox potato"
Atoqpa Siri	folk varietal (wild / non-consumable potato)
Atoqpa Kumpus	folk varietal (wild / non-consumable potato)
Ayacucho	Andean department (Peru)
Aymara	Andean language and ethnic group (altiplano region of Peru and Bolivia)
Ayni	labor sharing between families (symmetrical exchange)
Aynoqa(s)	see *Laymi(s)* (denomination Puno, Peru)
Ayrampu	cultivar name (potato; Adg)
Azul	blue (Spanish)
Azul Chiqchi Pasña	cultivar name (potato; Gon), literally "blue sparkled girl"
Azul Llumchuy Waqachi	cultivar name (potato; Adg), literally "blue makes daughter-in-law cry"
Azul Ñata	cultivar name (potato)
Azul Ñawi Pasña	cultivar name (potato; Gon), literally "blue-eyed girl"
Barbecho	type of soil tillage system
Camayoqs	see *Varayoqs*

Camote	sweetpotato (*Ipomoea batatas*; Latin American Spanish)
Camotillo	cultivar name (potato; Gon)
Campos	see *Varayoqs*
Canchan	cultivar name (potato; Tbr)
Capataz	supervisor of work to be delivered by common peasants for the hacienda
Capiro	cultivar name (potato; Tbr)
Casa Blanca	cultivar name (potato), literally "white house"
Castrovirreyna	province (department of Huancavelica)
Ccochaccasa	district (province of Angaraes)
Ccullukauna	old cultivar name (potato; Bertonio, 1612)
Chacma	see *Chacmeo*
Chacmeo	type of soil tillage system (minimal tillage)
Chakitaklla	Andean footplough
Chaqru	complete cultivar mixture
Charki	dried meat
Chaucha	vernacular name for *Solanum phureja*
Chaulina	cultivar name (potato)
Chayka Papa	see *Araq Papa* (denomination Yauyos, Lima, Peru)
Chaywa	fish (Quechua)
China	female (Quechua)
China Runtu	cultivar name (potato; Gon), literally "female egg"
China Wayru	cultivar name (potato)
Chingos	cultivar name (potato; Stn)
Chiqchi	sparkling (Quechua)
Chiqchi Pasña	cultivar name (potato; Gon), literally "sparkling girl"
Chiqchi Runtu	cultivar name (potato), literally "sparkling egg"
Chiwa	type of soil tillage system (minimal tillage)
Choque	potato (Aymara; altiplano region)
Chunya	cultivar name (potato)
Chuño	traditionally freeze-dried potato tubers
Churcampa	province (department of Huancavelica)
Chutta(s)	see *Laymi(s)*
Comunidad campesina	semi-autonomous farmer community
Dos de Mayo	research community (this thesis), literally "May the second"
Faena	communal working party
Gaspar	cultivar group (potato)
Guinda Masa Waqachi	cultivar name (potato; Adg), literally "purplish makes son-in-law cry"
Huamantanga	cultivar name (potato; Cha)
Huancavelica	Andean department (Peru), province (department of Huancavelica), name capital (department and province)
Huanuqueña	cultivar name (potato)
Huatoco	old cultivar name (potato; Bertonio, 1612)
Huayta Corral	research community (this thesis), literally "flower corral"
Huaytará	province (department of Huancavelica)
Ica	department (Peru) and name of its capital
Imicha	see *Chiwa*
Imilla	cultivar group (potato), literally "girl" (Aymara)
Inspectores	see *Varayoqs* (denomination Chopcca, Huancavelica, Peru), literally "inspectors"
Ipillu	cultivar group (potato)
Ipillu Culebra	cultivar name (potato; Stn)
Itaña	stinging nettle (Quechua; *Cajophora* spp.)
Jacaru	Andean language and ethnic group (Peru; Yauyos province)
Junín	Andean department (Peru)
Kanka Papa	cultivar name (potato)
Killi Wara	cultivar name (potato), literally "decorated trouser"
Killu	tuber sprout (Quechua)

Kipa Papa	escape or volunteer potato (Quechua)
Kora	herb (Quechua)
Kuchipa Akan	cultivar name (potato), literally "pig excrement"
Kulli	purple (Quechua)
Kumpus Siri	cultivar name (potato), bitter
Kusku	old cultivar name (potato; Bertonio, 1612)
Larga	cultivar name (potato)
Laymi(s)	sectoral fallow system (Quechua; Huancavelica, Peru)
Lelekkoya	see *Araq Papa* (denomination Bolivia)
Leona	cultivar name (potato; Adg)
Libertadores	research community (this thesis), literally "liberators"
Liberteña	cultivar name (potato; Tbr)
Limeña	cultivar name (potato; Gon)
Lircay	district (province of Angaraes)
Llumchuy Waqachi	cultivar group (potato), literally "makes daughter-in-law cry"
Luqlu	watery (Quechua)
Maca	native Andean root crop (*Lepidium meyenii*)
Machka machka	floury, mealy (Quechua)
Maco	cultivar name (potato; Adg)
Makin	paw (Quechua)
Manchaq	susceptible (Quechua; e.g., to diseases)
Manda(s)	see *Laymi(s)*
Mantaro	cultivar name (potato; Tbr), name of a river
Manwa	cultivar group (potato)
Maranis	see *Varayoqs*
Maria Bonita	cultivar name (potato; Tbr)
Mariva	cultivar name (potato; Tbr)
Maqta	male-youngster (Quechua)
Masa Waqachi	cultivar group (potato), literally "makes son-in-law cry"
Mashua	native Andean tuber crop (*Tropaeolum tuberosum*)
Mayki	tree (Quechua)
Michka	secondary (small) cropping season (Quechua)
Minka	help at harvest for payment in kind (asymmetrical exchange)
Misi(pa)	cat('s) (Quechua)
Misipa Makin	cultivar name (potato; Adg), literally "cat's paw"
Morado Gaspar	cultivar name (potato; Gon)
Morado Llumchuy Waqachi	cultivar name (potato), literally "purple makes daughter-in-law cry"
Muru	two-colored (Quechua)
Muru Gaspar	cultivar name (potato; Adg)
Muru Llumchuy Waqachi	cultivar name (potato; Cha), literally "two-colored makes daughter-in-law cry"
Muru Rosas	cultivar name (potato; Adg), literally "two-colored roses"
Muru Wayru	cultivar name (potato; Cha)
Murunki	cultivar name (potato), literally "two-colored"
Muyucamas	see *Varayoqs*
Muyuy(s)	see *Laymi(s)*
Nayrappoco	old cultivar name (potato; Bertonio, 1612)
Ñata	cultivar group (potato), compressed (Quechua)
Ñawi	tuber-eye (Quechua)
Ñawi sapa	big-eyed (Quechua)
Ñusta	female-youngster (Quechua)
Oca	native Andean tuber crop (*Oxalis tuberosa*)
Olluco	native Andean tuber crop (*Ullucus tuberosus*)
Pachacas	see *Varayoqs*
Pachamanka	typical dish of potato and meat prepared in an earth oven

Palta	cultivar group (potato), flat (Quechua)
Papa	Potato (Quechua, Latin American Spanish), refers to both the crop and tuber
Papa Curao	see *Araq Papa* (denomination Junín, Peru)
Papa del Zorro	wild / non-consumable potato (Spanish), literally "fox potato"
Papa Gentil	see *Araq Papa* (denomination central Andes of Peru)
Papa Tarpuy	cultivated / consumed potato (Quechua)
Pasña	cultivar group (potato), literally "girl"
Paucará	district (province of Acobamba)
Payapa Ankun	cultivar name (potato; Adg), literally "heel of an old lady"
Perricholi	cultivar name (potato; Tbr)
Peruanita	cultivar name (potato; Gon), literally "little Peruvian"
Pichi	small (Quechua)
Pichi Wayru	cultivar name (potato)
Pillpintu Pasña	cultivar name (potato; Adg), literally "butterfly girl"
Pongo	servant working obligatory for a hacienda owner
Pongos Grande	research community (this thesis)
Ppatticcalla	old cultivar name (potato; Bertonio, 1612)
Pucara	research community (this thesis)
Puka	red (Quechua)
Puka Chiqchi Pasña	cultivar name (potato; Gon), literally "red sparkling girl"
Puka Lagarto	cultivar name (potato; Adg), literally "red lizard"
Puka Llumchuy Waqachi	cultivar name (potato; Cha), literally "red makes daughter-in-law cry"
Puka Masa Waqachi	cultivar name (potato; Stn), literally "red makes son-in-law cry"
Puka Ñawi Gaspar	cultivar name (potato)
Puka Ñawi Pasña	cultivar name (potato), literally "red-eyed girl"
Puka Ñawi Tumbay	cultivar name (potato)
Puka Palta	cultivar name (potato; Adg), literally "red flat"
Puka Pasña	cultivar name (potato), literally "red girl"
Puka Qanchillu	cultivar name (potato; Juz), bitter
Puka Rosas	cultivar name (potato; Adg), literally "red roses"
Puka Wayru	cultivar name (potato)
Puma Coyllu	old cultivar name (potato; Bertonio, 1612)
Puma(pa)	puma('s) (Quechua)
Puma(pa) Makin	cultivar group and cultivar name (potato; Adg)
Puqya	culivar group and name (potato; Stn)
Qala Suytu	cultivar name (potato), literally "naked long"
Qala Wawa	cultivar name (potato; Adg), literally "naked child"
Qallun	tongue (Quechua)
Qanchillu	cultivar group (potato), bitter
Qanrachasqa	spotted (Quechua)
Qamya Kulli	violet (Quechua)
Qamya Puka	pink (Quechua)
Qaqay tullu	strong stem (Quechua)
Qaqi	see *Chiwa*
Qari tullu	strong stem (Quechua), literally "man stem"
Qatun	big (Quechua)
Qatun raphi	big leaf (Quechua)
Qatun tarpuy	main cropping season (Quechua), literally "big plantings"
Qatun Tumbay	cultivar name (potato)
Qatun ñawi	big tuber-eyes (Quechua)
Qawalla ñawiyuq	shallow-eyed (Quechua)
Qaywa	weaving tool (Quechua)
Qaywa siri	cultivar name (potato), bitter
Qeqorani	cultivar name (potato; Stn)
Qillu	yellow (Quechua)

Qillu Ipillu	cultivar name (potato; Adg)
Qillu Manwa	cultivar name (potato)
Qillu Pasña	cultivar name (potato), literally "yellow girl"
Qilli Qala Maqta	cultivar name (potato), literally "yellow naked youngster"
Qillu Rosas	cultivar name (potato), literally "yellow roses"
Qillu Suytu	cultivar name (potato), literally "yellow long"
Qillu Tumbay	cultivar name (potato; Gon)
Qillu Wayru	cultivar name (potato; Cha)
Qori Markina	cultivar name (potato; Adg)
Quechua	Andean language and ethnic group (Peru, Ecuador, Bolivia)
Quinoa	native Andean pseudo-grain (*Chenopodium quinoa*)
Qumir	green (Quechua)
Quyu	greened tuber (Quechua)
Raku tullu	thick stem (Quechua)
Raphi	leaf (Quechua)
Renacimiento	cultivar name (potato; Tbr)
Revolución	cultivar name (potato; Tbr)
Ritipa Sisan	cultivar group (potato), literally "snow glint"
Rosada Llumchuy Waqachi	cultivar name (potato; Cha), literally "pink makes daughter-in-law cry"
Rosas	cultivar group (potato), literally "roses"
Rumi	stone (Quechua)
Runtu(s)	cultivar name (potato; Gon), literally "egg(s)" or "testicle(s)"
Ruyru	round, kidney (Quechua)
Sacha	shrub or wild (Quechua)
Sacha col	see *Yuyo*
Saco Largo	cultivar name (potato), literally "long coat"
Sapi	root (Quechua)
Saqta Mati	typical dish; cultivar name (potato; Adg)
Sipu	wrinkled (Quechua; e.g., tuber skin)
Siri	cultivar group and name (potato), bitter
Sirina	cultivar name (potato; Cha), literally "mermaid"
Sisa	tuber sprout (Quechua)
Sortijillas	cultivar name (potato; Adg)
Suca	see *Chacmeo* (denomination Tayacaja, Huancavelica, Peru)
Suerte(s)	see *Laymi(s)*
Sunqu	tuber flesh (Quechua), literally "heart"
Surt'i(s)	see *Laymi(s)*
Suytu	cultivar group (potato), literally "long"
Suytu Alianza	cultivar name (potato)
Suytu Amaru	cultivar name (potato), literally "long snake"
Suytu Pasña	cultivar name (potato; Stn)
Suyu(s)	see *Laymi(s)*
Tarmeña	cultivar group (potato; Adg)
Tarwi	native Andean legume (*Lupinus mutabilis*)
Taqsaya raphi	small leaf (Quechua)
Tayacaja	province (department of Huancavelica)
Tipka	see *Chiwa* (denomination Tayacaja, Huancavelica, Peru)
Tipono	see *Araq Papa* (denomination Venezuela)
Trajin Waqachi	cultivar name (potato; Adg), literally "makes dress cry"
Troje	elevated wooden or adobe seed store bed containing seed tubers covered by straw (*Stipa ichu*)
Trueque	barter (Quechua)
Tullpuyasqa	pigmented (Quechua)
Tullu	stem (Quechua), literally "bone"
Tullu sapa	thick stem (Quechua)

Tumbay	cultivar group (potato)
Tupac Amaru	research community (this thesis), after the indigenous leader
Tuqra	supplement for chewing coca leaves (ball with quinoa ash)
Turno(s)	see *Laymi(s)*
Uchaya ñawi	small tuber-eye (Quechua)
Uchaya raphi	small leaf (Quechua)
Uchu	pepper (Quechua)
Uman	head (Quechua)
Unica	cultivar name (potato; Tbr)
Urqu	male (Quechua)
Urqu Tumbay	cultivar name (potato)
Uqi	brown (Quechua)
Uqi Ñata	cultivar name (potato)
Uqi Pasña	cultivar name (potato), literally "brown girl"
Uqi Ritipa Sisan	cultivar name (potato), literally "brown snow glint"
Varayoqs	assembly appointed guards looking after cropping areas (denomination Pongos Grande, Huancavelica, Peru)
Vila Kapi	old cultivar name (potato; Bertonio, 1612)
Villa	cultivar name (potato)
Villa Hermosa	research community (this thesis), literally "beautiful town"
Vlla Talla	old cultivar name (potato; Bertonio, 1612)
Wacha	escape or volunteer potato (Quechua)
Wachwa(pa)	goose('s) (Quechua)
Wachwapa Qallun	cultivar name, (potato, Adg), literally "goose's tongue"
Waka(pa)	cow('s) (Quechua)
Wakapa Qallun	cultivar name (potato; Adg), literally "cow's tongue"
Waña	cultivar group (potato), bitter
Wañu wañu tullu	weak stem (Quechua)
Wayru	cultivar group (potato)
Wayta	flower (Quechua)
Wayta Chuco	cultivar name (potato), literally "oblique flower"
Waytaq anaqta	Late flowering (Quechua)
Witqis	cultivar name (potato; Cha), literally "tears"
Yakuycha	see *Chiwa*
Yana	black (Quechua)
Yana Gaspar	cultivar name (potato; Adg)
Yana Ipillu	cultivar name (potato)
Yana Lastash	folk varietal (semi-wild / consumed potato)
Yana Llumchuy Waqachi	cultivar name (potato), literally "black makes daughter-in-law cry"
Yana Manwa	cultivar name (potato; Adg)
Yana Ñata	cultivar name (potato; Stn)
Yana Panwa	cultivar name (potato; Adg)
Yana Pasña	cultivar name (potato), literally "black girl"
Yana Ritipa Sisan	cultivar name (potato), literally "black snow glint"
Yana Siri	cultivar name (potato; Cur / Juz), bitter
Yana Sunqu Dusis	cultivar name (potato; Gon)
Yana Suytu	cultivar name (potato), literally "black long"
Yana Waña	cultivar name (potato; Cur), bitter
Yana Wayru	cultivar name (potato; Cha)
Yanu tullu	thin stem (Quechua)
Yauli	district (province of Huancavelica)
Yawar	blood (Quechua)
Yawar Ñawi Pasña	cultivar name (Quechua), literally "blood-eyed girl"
Yungay	cultivar name (potato; Tbr)

Yupanakuy	footplough (*chakitaklla*) competition between farmer groups and communities in *chacmeo* tillage
Yura	herbaceous plant (Quechua)
Yuraq	white (Quechua)
Yuraq Gaspar	cultivar name (potato; Adg)
Yuraq Ipillu	cultivar name (potato; Adg)
Yuraq Lastash	folk varietal (semi-wild / consumed potato)
Yuraq Lui	cultivar name (potato; Adg), bitter
Yuraq Manwa	cultivar name (potato; Adg), bitter
Yuraq Pasña	cultivar name (potato; Gon), literally "white girl"
Yuraq Qanchillu	cultivar name (potato)
Yuraq Ritipa Sisan	cultivar name (potato), literally "white snow glint"
Yuraq Siri	cultivar name (potato; Cur / Juz), bitter
Yuraq Sisa Wayru	cultivar name (potato; Cha)
Yuraq Suytu	cultivar name (potato), literally "white long"
Yuraq Suytu Siri	cultivar name (potato; Juz)
Yuraq Tumbay	cultivar name (potato; Stn)
Yuraq Waña	cultivar name (potato; Cur), bitter
Yuraq Wayru	cultivar name (potato)
Yuyo	weedy vegetable (*Brassica rapa*)
Zanco	dish (flour with pig fat)

Appendices

Appendix I. Formal morphological potato descriptors, characters, values, and their environmental stability

Descriptor	Character	Values	Environmentally Stable Yes	Environmentally Stable No
I. Plant habit	-	1) erect, 2.) semi-erect, 3)decumbent, 4) prostrate, 5) semi-rosette, 6) rosette		X
II. Leaf shape	Type of dissection	1) undissected, 2) pinnatilobed, 3) dissected	X	
	Number of primary lateral leaflets	0) absent, 1) 1 pair, 2) 2 pairs, 3) 3 pairs, 4) 4 pairs, 5) 5 pairs, 6) 6 pairs, 7) 7 pairs or more	X	
	Number of interjected leaflets between primary lateral leaflets	0) absent, 1) 1 pair, 2) 2 pairs, 3) 3 pairs, 4) 4 pairs or more		X
	Number of interjected leaflets among petiolule	0) absent, 1) 1 pair, 2) 2 pairs, 3) 3 pairs, 4) 4 pairs or more		X
III. Stem color	-	1) green, 2) green with few spots, 3) green with many spots, 4) pigmented with abundant green, 5) pigmented with little green, 6) reddish, 7) purplish		X
IV. Stem wing shape	-	0) absent, 1) straight, 2) undulate, 3) dentate	X	
V. Degree of flowering	-	0) without flower buds, 1) abortion of flower buds, 3) scarce flowering, 5) moderate flowering, 7) profuse flowering		X
VI. Corolla shape	-	1) stellate, 3) semi-stellate, 5) pentagonal, 7) rotate, 9) very rotate	X	
VII. Flower color	Predominant color	1) white, 2) red-pinkish, 3) red-purplish, 4) blue, 5) blue-purplish, 6) lilac, 7) purple, 8) violet		X

	Intensity of predominant color	1) bright, 2.) intermediate, 3) dark		X
	Secondary color	0) absent, 1) white, 2) red-pinkish, 3) red-purplish, 4) blue, 5) blue-purplish, 6) lilac, 7) purple, 8) violet		X
	Distribution of secondary color	0) absent, 1) white acumen - adaxial surface, 2) white acumen - abaxial surface, 3) white acumen - both surfaces, 4) star - adaxial surface, 5) stripes - adaxial surface, 6) stripes - abaxial surface, 7) stripes - both surfaces, 8) stippled, 9) few spots or points		X
VIII. Anther pigments	-	0) absent, 1) pigmented anther stripe (AS), 2) pigmented anther tip (AT), 3) AS and AT, 4) red-brown anthers	X	
IX. Pistil pigments	-	0) absent, 1) pigmented stigma (PS), 2) pigmented ovary (PO), 3) pigmented ovary wall (OW), 4) PS and PO, 5) PS and OW, 6) PO and OW, 7)PS, PO and OW, 8) other (pigmented style)	X	
X. Calyx color	-	1) green, 2) green with few spots, 3) green with many spots, 4) pigmented with abundant green, 5) pigmented with little green, 6) reddish, 7) purplish	X	
XI. Pedicel color	-	1) green, 2) only articulation pigmented, 3) slightly pigmented along the pedicel, 4) slightly pigmented along the pedicel and articulation, 5) pigmented above the articulation, 6) pigmented below the articulation, 7) predominantly pigmented and green articulation, 8) completely pigmented		X
XII. Berry color	-	1) green, 2) green with few white spots, 3) green with white streaks, 4) green with abundant white spots, 5) green with pigmented areas, 6) green with pigmented streaks, 7) predominantly pigmented	X	
XII. Berry shape	-	1) round, 2) round with mucro, 3) oval, 4) oval with mucro, 5) conical, 6) long conical, 7) pyriform	X	
XIV. Tuber skin color	Predominant color	1) white-cream, 2) yellow, 3) orange, 4) brown, 5) pink, 6) red, 7) red-purple, 8) purple, 9) blackish	X	
	Intensity of predominant color	1) bright, 2.) intermediate, 3) dark		X
	Secondary color	0) absent, 1) white-cream, 2) yellow, 3) orange, 4) brown, 5) pink, 6) red, 7) red-purple, 8) purple, 9) blackish	X	

	Distribution of secondary color	0) absent, 1) eyes, 2) eyebrows, 3) splashed, 4) scattered, 5) spectacled, 6) stippled, 7) few spots	X	
XV. Tuber shape	General shape	1) compressed, 2) round, 3) ovate, 4) obovate, 5) elliptic, 6) oblong, 7) long-oblong, 8) elongate	X	
	Unusual shape	0) absent, 1) flattened, 2) clavate, 3) reniform, 4) fusiform, 5) falcate, 6) spiral, 7) digitate, 8) concertina shaped, 9) tuberose	X	
	Eye depth	1) protruding, 3) shallow, 5) medium, 7) deep, 9) very deep	X	
XVI. Tuber flesh color	Predominant color	1) white, 2) cream, 3) yellow (bright), 4) yellow, 5) yellow (intense), 6) red, 7) purple, 8) violet		X
	Secondary color	0) absent, 1) white, 2) cream, 3) yellow (bright), 4) yellow, 5) yellow (intense), 6) red, 7) purple, 8) violet		X
	Distribution of secondary color	0) absent, 1) few spots, 2) scattered areas, 3) narrow vascular ring, 4) broad vascular ring, 5) vascular ring and medulla, 6) all flesh except medulla, 7) other (spotted)		X
XVII. Sprout color	Predominant color	1) white-greenish, 2) pink, 3) red, 4) purple, 5) violet	X	
	Secondary color	0) absent, 1) white-greenish, 2) pink, 3) red, 4) purple, 5) violet	X	
	Distribution of secondary color	0) absent, 1) at the base, 2) at the apex, 3) lightly scattered throughout, 4) heavily scattered throughout, 5) in the buds	X	

Adapted from: Gómez, 2000; Huamán and Gómez, 1994.

Appendix II. Vernacular names in Quechua, Aymara, and Spanish for wild potato species

	Vernacular name	Written variants	Source
Quechua	*Allqu Papa*	Alkko, Alcco	8
	Ama Papa	*Amaa*	8
	Añas(pa) Papa	*Añaz*	3, 7, 8, 13
	Araq Papa	*Aracc*	8
	Atoq(pa) Papa	*Atocc, Ato'q, Atoj, Atokcpa*	1, 6, 7, 8, 9, 11, 12, 13, 14
	Atoqpa Akshu		4, 5
	Auqui(llo) Papa		8
	Aya Papa		7, 8, 13
	Kita Papa	*Kkita, K'iti, K´ita, K'itha, Quita*	1, 7, 8, 9, 11
	Kapu	*Kkapu*	7
	Mallku Papa		14
	Maula Papa		8
	Ñaupa Papa		8
	Pisqu Papa	*Pishgo, Piscco, Pishu*	8
	Pisqu Akshu	*Pishgo, Piscco, Pishu*	8
	Purum Papa	*Purun*	8
	Qacha Papa	*Jacha*	8
	Qampatu Papa	*Jampatu*	8, 9
	Qupay(pa) Papa	*Jupay(pa)*	8
	Sacha Papa		3, 11
	Uchika		7
	Utu(pa) Papa	*Llutt'u*	8, 9
Aymara	*Apharu (Choque)*	*Apfaru, Aparu, Aparoma, Apharuma*	1, 2, 7, 8, 9, 10, 11, 12
	(Gentil) Achochil Choque		8, 9
	Ipi Amka	*Ipi*	1, 2, 7
	Kipa Choque	*Ckipa, Quipa*	9
	Kita	*Kkita, K'iti, K´ita, K'itha, Quita*	12
	Llillicoya		7
	Puyuli		8
Spanish	*Chaucha de Zorro*		8
	Cuenca Papa		8
	Papa Cholón		8
	Papa Cimarrona	*Cimarrón*	8, 13
	Papa de Abuelo		8
	Papa de Chancho		9
	Papa (del) Gentil		8, 13
	Papa del Inca		8
	Papa de Loma(s)		8
	Papa del Macho		8
	Papa de(l) Monte		8
	(Papa) Name		8
	Papa de Pájaro		8
	Papa del Puro Macho		8
	Papa de Wisco		9
	Papa del Zorro		8, 9, 13

Sources: 1. Ballón Aguirre and Cerrón-Palomino (2002); 2. Bertonio (1612); 3. Brack Egg (1999); 4. Brush (1980); 5. Brush *et al.* (1980), 6. Cusihuaman (1976); 7. Hawkes (1947); 8. Ochoa (1999); 9. Ochoa (2001); 10. PRATEC (1997); 11. PRATEC (1999a); 12. PRATEC (1999b); 13. Soukup (1994); 14. Vargas (1936)

Appendix III. Vernacular names of wild potato species in Quechua, Aymara, and Spanish, and the formal species and regions for which they were reported by Carlos Ochoa (1999, 2001)

	Vernacular name	Species and location (department, country)
Quechua	*Allqu Papa*	*Solanum bukasovii* (Cusco, Peru); *S. marinasense* (Cusco, Peru); *S. megistacrolobum* (Cusco, Peru); *S. sparsipilum* (Bolivia); *S. sucrense* (Chuquisaca, Bolivia)
	Ama Papa	*S. acroglossum* (Huánuco, Peru); *S. ariduphilum* (Huánuco, Peru); *S. chomatophilum* (Huánuco, Peru)
	Añas(pa) Papa	*S. bukasovii* (Puno, Peru); *S. immite* (La Libertad, Peru); *S. medians* (Lima, Peru); *S. multiinterruptum* (Lima, Peru)
	Araq Papa	*S. raphanifolium* (Cusco, Peru); *S. sparsipilum* (Cusco, Peru)
	Atoq(pa) Papa	*S. acaule* (Cusco, Peru); *S. augustii* (Ancash, Peru); *S. bukasovii* (Ayacucho and Cusco, Peru); *S. huancavelicae* (Huancavelica, Peru); *S. lignicaule* (Cusco, Peru); *S. multiinterruptum* (Ancash, Peru); *S. sogarandinum* (Ancash, Peru); *S. sparsipilum* (Cusco, Peru); *S. velardei* (Apurimac, Peru)
	Atoqpa Akshu	-
	Auqui(llo) Papa	*S. acroglossum* (Pasco, Peru); *S. ambosinum* (Huánuco, Peru)
	Aya Papa	*S. albicans* (Cariguarazo, Ecuador)
	Kita Papa	*S. boliviense* (Chuquisaca, Bolivia); *S. bukasovii* (Ayacucho and Puno, Peru); *S. megistacrolobum* (Cusco, Peru); *S. raphanifolium* (Cusco, Peru); *S. sparsipilum* (Cusco and Puno, Peru)
	Kapu	-
	Mallku Papa	-
	Maula Papa	*S. bukasovii* (Cusco, Peru)
	Ñaupa Papa	*S. lignicaule* (Cusco, Peru)
	Pisqu Papa	*S. albicans* (Cajamarca, Peru); *S. chomatophilum* (Huánuco, Peru); *S. sparsipilum* (Bolivia)
	Pisqu Akshu	*S. bukasovii* (Junín, Peru)
	Purum Papa	*S. ambosinum* (Pasco, Peru); *S. scabrifolium* (Huanuco, Peru)
	Qacha Papa	*S. salasianum* (Huánuco, Peru)
	Qampatu Papa	*S. raphanifolium* (Cusco, Peru); *S. sparsipilum* (Bolivia)
	Qupay(pa) Papa	*S. acaule* (Junín and Pasco, Peru); *S. bukasovii* (Pasco, Peru); *S. dolichocremastrum* (Ancash, Peru)
	Sacha Papa	-
	Uchika	-
	Utu(pa) Papa	*S. berthaultii* (Chuquisaca, Bolivia); *S. sparsipilum* (Cusco, Peru); *S. tarapatanum* (Cusco, Peru)
Aymara	*Apharu (Choque)*	*S. acaule* (La Paz, Bolivia; Puno, Peru); *S. berthaultii* (Cochabamba, Bolivia); *S. chacoense* (Santa Cruz, Bolivia); *S. sparsipilum* (Cochabamba and La Paz, Bolivia); *S. tapojense* (Puno, Peru)
	(Gentil) Achochil Choque	*S. candolleanum* (La Paz, Bolivia)
	Ipi amka	-
	Kipa Choque	*S. flavoviridens* (La Paz, Bolivia); *S. sparsipilum* (La Paz, Bolivia)
	Kita	-
	Llillicoya	-
	Puyuli	*S. limbaniese* (Puno, Peru)
Spanish	*Chaucha de Zorro*	*S. chomatophilum* (La Libertad, Peru)
	Cuenca Papa	*S. bukasovii* (Pasco, Peru)
	Papa Cholón	*S. laxissimum* (Huánuco, Peru)
	Papa Cimarrona	*S. medians* (Lima, Peru); *S. multiinterruptum* (Lima, Peru); *S. neoweberbaueri* (Lima, Peru)

Papa de Abuelo	*S. bukasovii* (Ayacucho, Peru); *S. cantense* (Lima, Peru); *S. multiinterruptum* (Lima, Peru)
Papa de Chancho	*S. tarijense* (Tarija, Bolivia)
Papa (del) Gentil	*S. blanco-galdosii* (Cajamarca, Peru); *S. bukasovii* (Junin, Peru); *S. cantense* (Lima, Peru); *S. chomatophilum* (Ancash, Peru); S. *dolichocremastrum* (Ancash, Peru); *S. humectophilum* (Amazonas, Peru); *S. hypacrarthrum* (Lima, Peru); *S. irosinum* (Cajamarca, Peru); *S. multiinterruptum* (Ancash, Peru); *S. simplicissimum* (Lima, Peru); *S. wittmackii* (Lima, Peru)
Papa del Inca	*S. urubambae* (Cusco, Peru)
Papa de Loma(s)	*S. chancayense* (Lima, Peru); *S.mochiquense* (La Libertad, Peru)
Papa del Macho	*S. humectophilum* (Amazonas, Peru)
Papa de(l) Monte	*S. ingaefolium* (Piura, Peru); *S. laxissimum* (Huánuco, Peru); *S. santolallae* (Cusco, Peru); *S. urubambae* (Cusco, Peru)
(Papa) Name	*S. huarochiriense* (Lima, Peru); *S. simplicissimum* (Lima, Peru)
Papa de Pájaro	*S. peloquinianum* (Ancash, Peru)
Papa del Puro Macho	*S. burkartii* (Amazonas, Peru)
Papa de Wisco	*S. raquialatum* (Piura, Peru)
Papa del Zorro	*S. anamatophilum* (Ancash, Peru); *S. bukasovii* (Ayacucho, Peru); *S. candelarianum* (Santa Cruz, Bolivia); *S. chacoense* (Santa Cruz, Bolivia); *S. chiquidenum* (Cajamarca and La Libertad, Peru); *S. chomatophilum* (Huanuco, Peru); *S. immite* (La Libertad, Peru); *S. incahuasinum* (Lambayeque, Peru); *S. jalcae* (La Libertad, Peru); *S. lopez-camarenae* (Cajamarca, Peru); *S. medians* (Lima, Peru); *S. mochiquense* (Cajamarca, Peru); *S. multiinterruptum* (Lima, Peru); *S. neocardenasii* (Santa Cruz, Bolivia); *S. nubicola* (Huanuco, Peru); *S. olmosense* (Lambayeque, Peru); *S. orophilum* (Ancash, Peru); *S. piurae* (Piura, Peru); *S. sogarandinum* (La Libertad, Peru); *S. tarijense* (Tarija, Bolivia)

Source: Ochoa (1999, 2001)

Appendix IV. Vernacular names in Quechua, Aymara, and Spanish for semi-wild potato species and escapes

Semi-wild	Name	Written variants	Sources
Quechua	*Araq Papa*	*Arak, Aracca, Ara'qua, Araj, Araqa*	Ballón Aguirre and Cerrón-Palomino (2002); Cusihuaman (1976); Hawkes (1947); PRATEC (1999a); Vargas (1936)
	Allqu Papa	*Alkko Papa*	Hawkes (1947)
	Chayka Papa		Pers. obs.
	Curo		PRATEC (1999b)
	Kurao Akshu		Brush (1980); Brush *et al.* (1980)
	Machuq Papa	*Machucc*	Vargas (1936)
	Pisqu Papa	*Ppisco Papa*	Hawkes (1947)
Aymara	*Japu*		Bertonio (1612); Hawkes (1947)
	Lelekkoya		Ochoa, 2001
Spanish	*Papa Curao*		Pers. obs.
	Papa de Abuelo		Brack Egg (1999)
	Papa Gentil		Cabieses (1995), Pers. obs.; PRATEC (1999a)
	Semillu		Ochoa, 2001
Escapes	**Name**	**Written variants**	**Sources**
Quechua	*Papa Wacha*		Pers. obs.
	Kipa Papa		PRATEC (1999a)
	Cachu		Hawkes (1947)
	Koyu Papa		Hawkes (1947)
	Siwa	*Sihua*	Hawkes (1947)
Aymara	*Anakachu*		Hawkes (1947)
	Kea	*Kkea*	Ballón Aguirre and Cerrón-Palomino (2002); Bertonio (1612); Hawkes (1947)
	Kipa (Choque)	*Kkipa, K'hipa (Choque)*	Hawkes (1947); PRATEC (1997); PRATEC (1999a); PRATEC (1999b)
Spanish	*Kipa*		Pers. obs.
	Wacha		Pers. obs.

Appendix V. Basic information of regular markets visited and vendors surveyed

Market	Locality		Frequency	Number of:		Sample size (n)	Type of vendors surveyed (%)		Type of presentation by vendors (%)		
	Province	District		Potato vendors	Daily visitors		Wholesaler	Retailer	Stall	Pave-ment	Truck
Ccochaccasa Market	Angaraes	Ccochaccasa	Weekly	8	300	5	60.0	40.0	-	60.0	40.0
Huancavelica Sunday Market	Huancavelica	Huancavelica	Weekly	15	650	8	87.5	12.5	12.5	-	87.5
Paucara Sunday Market	Acobamba	Paucara	Weekly	15	500	12	50.0	50.0	33.3	58.3	8.3
Pampas Sunday Market	Tayacaja	Pampas	Weekly	20	650	16	43.8	56.3	12.5	50.0	43.8
Lircay Sunday Market	Angaraes	Lircay	Weekly	10	600	9	33.3	66.7	-	88.9	11.1
Huancavelica Saturday Market	Huancavelica	Huancavelica	Weekly	5	250	3	33.3	66.7	-	66.7	33.3
Yauli Saturday Market	Huancavelica	Yauli	Weekly	2	100	2	-	100	50.0	50.0	-
Pasos Saturday Market	Tayacaja	Pasos	Weekly	6	350	3	33.3	66.7	-	100	-
Permanent Market Huancavelica	Huancavelica	Huancavelica	Daily	24	650	15	-	100	80.0	20.0	-
Overall						**73**	**38.4**	**61.6**	**27.4**	**47.9**	**24.7**

Appendix VI. Basic information of seed fairs visited

Fair	Organization[1]	Date visited	Year first fair	Locality		No. participants		Type of competitions[2]				Prizes / Incentives[3]			
				District	Province	Crops	Native Potato	BD	LD	HC	LS	TO	KU	FS	FE
V Feria Agricola	MUN, MINAG	16-07-2005	2001	Caja	Acobamba	7	2	X	X	X		X		X	
National Potato Day	MUN, MINAG	29 / 30-05-2006	2006	Paucara	Acobamba	29	19	X	X	X		X	X	X	
VIII Expo Agro Lircay	MUN, MINAG	17 / 18-06-2006	1999	Lircay	Angaraes	15	8	X	X		X	X	X	X	
XII Expo Agro Yauli	MINAG	17-06-2006	1995	Yauli	Huancavelica	10	8	X	X		X	X	X	X	
III Feria Agropecuaria	MUN, MINAG	06-05-2006	2004	Huayllay Grande	Angaraes	10	6	X	X		X		X	X	
II Festi Agro Huancavelica	RG, MINAG, PRONAMACHS, NGO's	24 / 27-06-2006	1990	Huancavelica	Huancavelica	26	19	X	X	X	X	X	X		
Concurso de Semillas	MUN, MINAG, NGO, INIA, CIP	11-06-2006	2006	Yauli	Huancavelica	28	24	X	X				X		
IV Feria Huanaspámpa	MUN, MINAG	08-06-2006	2003	Acoria	Huancavelica	6	4	X		X	X			X	
Expo Yauris 2006	MUN, MINAG, NIA	25 / 27-07-2006	1980	Huancayo	Huancayo	8	4	X	X	X	X	X			
Feria Agropecuaria	MUN, MINAG	22 / 23-07-2006	2002	Pampas	Tayacaja	7	4	X			X	X			X

[1] MUN = Municipality, MINAG = Ministry of Agriculture, RG = Regional Government, PRON = PRONAMACHCS (*Programa Nacional de Manejo de Cuencas y Conservación de Suelos*), INIA = *Instituto Nacional de Investigación Agraria*; NGO = Non Governmental Organization; CIP = International Potato Center; [2] BD = biodiversity (agricultural), LD = local dishes, HC = handicrafts, LS = livestock; [3] TO = tools, KU = kitchen utensils, FS = food stuff, FE = fertilizers

Appendix VII. Potato cultivars offered by vendors at regular markets (2005; n=72)

Cultivar	Cultivar Category			Vendors offering cultivar (%)	Day Volume Offered (kg)				Prices[1] (Peruvian Soles / kg)			
	Improved	Native-floury	Native-bitter		Av.	SD (±)	Min.	Max.	Av.	SD (±)	Min.	Max.
'Ajo Suytu'		X		9.7	190	221	18	500	1.03	0.08	1.00	1.20
'Amarillis'	X			23.6	661	1141	40	5000	0.61	0.10	0.40	0.75
'Amarilla Runtus'		X		31.9	977	1386	1	5000	0.85	0.21	0.60	1.20
'Amarilla Crespa'		X		5.6	1245	1128	80	2400	0.85	0.10	0.80	1.00
'Andina'	X			27.8	754	978	50	3500	0.61	0.09	0.50	0.75
'Camotillo'		X		25.6	145	64	80	200	0.90	0.14	0.70	1.00
'Canchan'	X			83.3	722	1124	30	6000	0.64	0.18	0.40	0.90
'Capiro'	X			8.3	478	290	120	1000	0.63	0.10	0.50	0.75
Chaqru (*)		X		11.1	117	157	30	500	0.70	0.24	0.40	1.00
'Chaulina'		X		1.4	200	-	200	200	0.80	-	0.80	0.80
'Cheqche Pasña'		X		1.4	10	-	10	10	0.60	-	0.60	0.60
'Chunya'		X		2.8	32	11	24	40	0.65	0.21	0.50	0.80
'Kuchipa Akan'		X		1.4	12	-	12	12	1.00	0.00	1.00	1.00
'Huanuqueña'		X		5.6	588	118	500	750	0.81	0.13	0.70	1.00
'Wayru'		X		33.3	315	288	18	1000	0.82	0.14	0.60	1.20
'Witqis'		X		1.4	5	-	5	5	0.80	-	0.80	0.80
'Imilla'		X		1.4	4800	-	4800	4800	0.90	-	0.90	0.90
'Larga'		X		41.7	476	749	10	4000	0.95	0.14	0.60	1.20
'Liberteña'	X			5.6	395	122	280	500	0.68	0.10	0.60	0.80
'Peruanita'		X		26.4	840	1634	80	7500	0.94	0.14	0.70	1.20
'Perricholi'	X			27.8	914	1281	100	4000	0.63	0.11	0.40	0.80
'Traqin Waqachi'		X		1.4	20	-	20	20	0.80	-	0.80	0.80
'Renacimiento'	X			1.4	100	-	100	100	0.60	-	0.60	0.60
'Revolución'	X			2.8	256	345	12	500	0.55	0.07	0.50	0.60
'Siri'			X	1.4	180	-	180	180	1.80	-	1.80	1.80
'Tumbay'		X		2.8	360	339	120	600	0.80	-	0.80	0.80
'Villa'		X		11.1	346	314	40	850	0.61	0.15	0.50	0.75
'Yungay'	X			72.2	689	977	24	4500	0.65	0.14	0.40	1.00

[1] Prices based on ware and seed potatoes between November and December 2005 (exchange rate 1 USD $ = 3.33 Soles); * *Chaqru* = complete mixtures of native-floury cultivar

Appendix VIII. Fields affected, damage perceived and levels of yield reduction after a severe regional frost for selected communities in Huancavelica

Community	N	Improved cultivars			Native-floury cultivars (single cultivar stands)			Native-floury cultivars (mixed cultivar stands)			Native-bitter cultivars		
		Fields affected (%)	Perceived level of damage[1] (%)	Level of yield reduction[2] (%)	Fields affected (%)	Perceived level of damage[1] (%)	Level of yield reduction[2] (%)	Fields affected (%)	Perceived level of damage[1] (%)	Level of yield reduction[2] (%)	Fields affected (%)	Perceived level of damage[1]	Level of yield reduction[2]
Pucara	26	100	84.3	81.3	100	81.0	74.7	100	70.0	63.3	100	75.0	72.8
Villa Hermosa	24	100	81.8	56.4	97.1	79.2	77.5	97.8	87.0	81.4	100	83.1	72.2
Chuñunapampa	25	98.0	66.6	69.5	100	64.9	63.1	100	60.2	62.2	100	70.2	59.9
Sotopampa	25	79.5	69.2	76.0	95.5	89.1	82.6	77.5	75.4	73.6	100	97.0	11.1
Ccasapata	30	92.3	64.8	65.2	92.6	62.4	64.9	91.3	66.5	74.8	95.2	82.4	72.0
Santa Rosa	25	100	62.4	78.5	100	55.8	78.7	100	52.9	81.8	72.0	49.4	85.0
Ccollpaccasa	25	100	82.3	85.6	98.3	79.1	81.5	98.6	80.9	82.8	100	83.9	83.9
Huachua	25	86.4	55.7	79.1	81.9	49.6	70.7	93.5	64.4	67.7	92.0	60.7	46.4
Chopccapampa	50	100	85.1	85.9	100	88.7	91.1	100	91.0	90.6	100	93.8	95.1
Limapampa	25	89.5	87.2	80.7	96.2	86.5	76.3	97.6	79.2	71.4	94.4	94.3	92.2
Overall	**280**	**95.3**	**76.7**	**75.8**	**95.8**	**70.5**	**76.2**	**95.5**	**72.7**	**77.2**	**92.6**	**72.9**	**70.4**

[1] = at the moment when the frost affected (17-02-2007); [2] = at the moment of harvest

Appendix IX. Scale of cultivar loss for potato and three cultivar categories after a severe regional frost

Community	N	Potato overall					Improved cultivars					Native-floury cultivars					Native-bitter cultivars				
		Farmers having cultivars (%)	No. cultivars lost				Farmers having cultivars (%)	No. cultivars lost				Farmers having cultivars (%)	No. cultivars lost				Farmers having cultivars (%)	No. cultivars lost			
			Av.	SD (±)	Min.	Max.		Av.	SD (±)	Min.	Max.		Av.	SD (±)	Min.	Max.		Av.	SD (±)	Min.	Max.
Pucara	26	44.0	3.0	2.4	1	7	19.2	1.2	0.4	1	2	23.1	4.5	2.4	2	7	-	-	-	-	-
Villa Hermosa	24	50.0	7.3	4.3	1	15	0	-	-	-	-	50.0	7.2	4.2	1	14	4.2	1.0	0	1	1
Chuñunapampa	25	60.0	2.4	1.6	1	7	0	-	-	-	-	56.0	2.4	1.4	1	6	12.0	1.0	0	1	1
Sotopampa	25	76.0	2.7	1.3	1	7	40.0	1.2	0.4	1	2	72.0	2.2	1.6	1	7	16.0	1.0	0	1	1
Ccasapata	30	66.7	3.5	1.9	1	6	10.0	1.0	0	1	1	60.0	2.9	1.8	1	7	30.8	1.3	0.5	1	2
Santa Rosa	25	88.0	5.0	2.7	1	13	24.0	1.7	0.5	1	2	96.0	4.5	2.3	2	11	8.0	1.0	0	1	1
Ccollpaccasa	25	100	6.7	2.4	2	12	36.0	1.3	0.5	1	2	96.0	5.8	2.8	1	12	32.0	1.1	0.4	1	2
Huachua	25	76.0	5.6	3.0	1	11	24.0	1.7	0.8	1	3	80.0	4,7	2.4	1	10	28.0	1.3	0.8	1	3
Chopccapampa	50	82.0	4.6	2.6	1	10	60.0	1.2	0.4	1	2	80.0	3.9	2.1	1	10	14.0	1.3	0.5	1	2
Limapampa	25	92.0	5.1	3.0	1	10	64.0	1.4	0.5	1	2	72.0	5.2	2.4	1	8	12.0	1.0	0	1	1
Overall	**280**	**75.1**	**4.7**	**2.9**	**1**	**15**	**30.4**	**1.3**	**0.5**	**1**	**3**	**69.3**	**4.3**	**2.7**	**1**	**14**	**15.4**	**1.2**	**0.4**	**1**	**3**

Summary

In-situ conservation

Two types of *in-situ* conservation of crop genetic resources can be distinguished: farmer-driven and externally driven. The first is subject of this thesis and refers to the persistence of potato genetic resources in areas where everyday practices of farmers maintain diversity on-farm. The second concerns the more recent phenomenon of Research & Development (R&D) interventions which aim to support *in-situ* conservation by farmers. In this study, farmer-driven *in-situ* conservation of the potato in the central Andes of Peru is investigated at different system levels from alleles, cultivars, and botanical species up to the level of the landscape, as well as the interconnected seed and food systems. Dimensions of time and space are inferred upon by taking both annual and longer-term spatial patterns into account. Further, diversity is linked to selected farmer-based and external drivers.

Objective and study area

The overall objective of the study is to enhance our understanding of farmer-driven *in-situ* conservation and the context in which it takes place. The main field research was conducted between 2003 and 2006 in eight farmer communities following a north-south transect through the department of Huancavelica. Communities were selected on the basis of distribution and distance along the north-south transect, tradition of potato cultivation, ethnicity, and relative distance from major markets or cities. Depending on the specific dimension of farmer-driven *in-situ* conservation investigated, a range of different methods and tools were used. Chapter 1 provides a brief description of the study area and an overview of the research methods used.

Species, cultivar and allelic diversity

In chapter 2 the species, morphological and molecular diversity of Andean potatoes in Huancavelica is treated at different scales of conservation: farmer family, community, geographically distanced, regional, *in-situ* and *ex-situ* subpopulations. The infraspecific diversity of *in-situ* collections was characterized using morphological descriptor lists and 18 polymorphic microsatellite markers (SSR). Botanical species were determined through ploidy counts in combination with morphological keys. Datasets were used for descriptive statistics, (dis)similarity analysis, dendrogram construction, cophenetic analysis, matrix correlations calculations (Mantel tests), and Analysis of Molecular Variance (AMOVA).

Results show that farmers in Huancavelica maintain high levels of species, morphological and molecular diversity. All cultivated potato species with the exception of *Solanum phureja* and *Solanum ajanhuiri* proved to be present. Tetraploid species were most abundant followed by diploids, triploids and pentaploids. A total of 557 morphologically unique cultivars were identified based on the morphological characterization of 2,481 accessions belonging to 38 *in-situ* collections. Genetic fingerprinting of 989 accessions belonging to 8 *in-situ* collections resulted in the identification of 406 genetically unique cultivars. AMOVA shows that the principal source of molecular variation is found within rather than between geographically distanced and farmer family subpopulations. No evidence of genetic erosion was found as the contemporary regional *in-situ* population and a geographically restricted subset of CIP´s *ex-situ* core collection share 98.8% of allelic diversity. Yet, *in-situ* collections contain numerous unique genotypes.

Indigenous biosystematics

The indigenous biosystematics of potatoes (folk taxonomy, folk descriptors and nomenclature) is investigated in chapter 3. The chapter includes an extensive literature review on the subject. Folk taxonomy was investigated with the use of grouping exercises with farmers, participant observation, and comparison

of farmer-recognized groups with formal classification based on morphological descriptors and 18 polymorphic microsatellite markers (SSR). Analysis of the latter was based on (dis)similarity analysis, dendrogram construction and consequent levels of coherent clustering by folk taxonomic entity (folk specific and varietal taxon). Ethnobotanical free and indicated listing exercises with farmers were used for research concerning folk descriptors. Descriptive statistics were used for analysis and interpretation. Nomenclature was investigated by applying nomenclature surveys, participant observation and basic ethnolinguistic analysis of regional names.

Folk taxonomy of the potato consists of no less than five ranks. The folk generic rank is composed of three taxa: *Araq Papa* (semi-wild / consumed), *Papa Tarpuy* (cultivated / consumed), and *Atoq Papa* (wild / not consumed). Folk specific taxa (= cultivar groups) and varietal taxa (= cultivars) within the generic taxon of *Papa Tarpuy* are abundant. Use categories and agroecological criteria are of little importance in the folk taxonomical system of the potato. Folk varietal taxa cluster well when using formal morphological descriptors; folk specific taxa less so. A moderate concordance, albeit with considerable exceptions, exists between folk specific or varietal taxa and their genetic make-up as characterized with molecular markers (18 SSR microsatellites). The coherence of clustering in a dissimilarity tree varies for each folk specific or varietal taxon considered. Farmers use 22 plant and 15 tuber folk descriptors with recognized character states in the Quechua language. Farmers are well able to recognize specific cultivars based on aboveground plant parts only (without exposing tubers). Nomenclature is regionally consistent for common cultivars, while inconsistent for scarce cultivars. Primary cultivar names (nouns) generally refer to a folk specific taxon through predominant metaphorical reference to tuber shape. Secondary cultivar names (adjectives) predominantly provide direct reference to tuber color.

Annual spatial patterns

Annual spatial management of the potato consists of cropping and labor calendars, field scattering practices, and genotype by environmental management. These three dimensions of agrobiodiversity management are explored in chapter 4. A structured survey was conducted to investigate the potato cropping and labor calendars. Participatory cartography resulted in the detailed mapping of 601 scattered potato fields, including their cultivar content, belonging to a total of 122 households. A genotype by environment (GxE) experiment employing 4 environments and 31 cultivars was conducted following an altitudinal transect. Data obtained was analyzed and interpreted using descriptive statistics, correlation analysis, Geographical Information Systems (GIS), Additive main Effects and Multiplicative Interaction (AMMI) analysis, and analysis of variance (ANOVA).

The annual distribution of tasks and labor is primarily an adaptation to the single-season rain-fed character and climate extremes of high-altitude agriculture. Three different footplough-based tillage systems allow farmers to efficiently manage scarce labor availability for soil preparation. Native-floury, native-bitter and improved potato cultivars show considerable overlap concerning their altitudinal distribution patterns. The notion that these cultivar categories occupy separate production spaces (so-called "altitudinal belts") is rejected as results show that differences between the altitudinal medians for areal distribution by altitude of the different cultivar categories are modest (chapter 4). Field scattering is based on a combined logic which results in a patchy distribution of potato genetic diversity across the agricultural landscape. Depending on the community, farmers annually crop an average of 3.2 to 9.1 potato fields measuring between 660 to 1,576 m² and containing up to a hundred cultivars per field. However, neither field scattering nor the management of high levels of diversity by farmers is a direct consequence of niche adaptation as most cultivars are versatile (chapter 4). Rather, it is suggested that farmers conduct annual spatial management by deploying combined tolerance and resistance traits imbedded in particular cultivar combinations in order to confront the predominant biotic and abiotic stresses present in different agroecologies. Andean farmers manage GxE adaptation for overall yield stability rather than fine-grained environmental adaptation of native cultivars.

Dimensions of land use

Three specific dimensions of potato land use were researched in order to gain insights into possible contemporary changes affecting the *in-situ* conservation of potato genetic resources: land use tendencies, rotation designs and their intensity, and sectoral fallowing systems (chapter 5). The main research method involved participatory cartography using printed poster-size high-resolution Quickbird satellite images combined with in-depth consultation through interviews and focus group meetings with members of the communities. A total of 4,343 fields and their 1995-2005 crop contents were mapped. The evolution over a

30-year time-span (1975-2005) of traditional sectoral fallow systems ("diversity hotspots") was documented for each community. Data was analyzed using descriptive statistics and Geographical Information Systems (GIS). Processes of change and adaptive innovation were documented by building case studies.

Land use tendencies between 1995 and 2005 shows that the total cropping area dedicated to improved cultivars has grown fast while the area dedicated to native-floury and native-bitter cultivars has remained more or less stable. Reduced fallow periods for existing fields and the gradual incorporating of high-altitude virgin pasture lands sustain areal growth. Areal growth is particularly fast at extreme altitudes between 3,900 and 4,350 m. However, fallow periods at these altitudes are still relatively long compared to fields at lower altitudes. Results show that fallowing rates increase by altitude for all cultivar categories, but tend to be lowest for improved cultivars followed by native-floury and native-bitter cultivars. There is no evidence of a straightforward replacement of one cultivar category by another resulting in the replacement and loss of infraspecific diversity. Inquiry into the dynamics of sectoral fallow systems over a 30 year period evidences the gradual disintegration and abandonment of these systems rich in cultivar diversity. They are replaced by more individualist management regimes based on household decision making. Nowadays, the spatial patterning of potato genetic diversity within the agricultural landscape is increasingly characterized by patchy distribution patterns rather than its concentration within a single communal sector. Where sectoral rotation designs survive local innovations have been adopted.

Farmer seed systems

Farmer seed systems can be conceived as an overlay of crop genetic diversity determining its temporal and spatial patterning. Chapter 6 investigates the relation between selected farmer seed system components (storage, health and procurement) and infraspecific diversity of potato in Huancavelica. A sampling exercise was carried out in farmer seed stores in order to gain insight into the internal organization of seed stores and how this relates to the management of infraspecific diversity. Virus infection rates were determined by taking seed tuber samples of diverse cultivars from farmer's storage facilities. ELISA tests were conduced for APMoV, PLRV, PMTV, PVY and PVX. Seed procurement was investigated through a series of structured surveys focusing on household seed exchange, the role of regular markets and biodiversity seed fairs, and seed provision after severe regional frost. Data was analyzed and interpreted using descriptive statistics.

Potato seed stores contain different seed lots, reflecting the rationales underlying management of cultivar diversity at the field level and the overall structure of infraspecific diversity. Seed health of farmer conserved cultivar stocks in Huancavelica is affected by *Diabrotica* leaf beetle and contact transmitted viruses (APMoV, PVX) while aphid and powdery scab transmitted viruses (PMTV, PLRV, PVY) are of limited importance. During normal years without extreme events seed exchange of native-floury cultivars is practiced by few households and characterized by a limited number of transactions involving small quantities of seed of few cultivars covering relatively short distances. Native-bitter and uncommon native-floury cultivars are rarely exchanged and generally reproduced year after year by the same households that maintain them. High-altitude diversity-rich communities tend to be net seed exporters. However, the capacity of the farmer seed system to annually widely supply and distribute infraspecific diversity is limited. Regular markets have a decentralized capacity to supply and widely distribute seed of a limited number of well-known cultivars. Frequencies of seed exchange at biodiversity seed fairs are low and involve small quantities of a few uncommon cultivars. The resilience of the farmer seed system to cope with severe regional seed stress is insufficient for households to be able to restore volumes and cultivar portfolios within a short period of time.

The potato-based food system

The role of biodiverse potatoes within the human diet in Huancavelica is investigated in chapter 7. Analysis to determine the dry matter, gross energy, crude protein, iron (Fe) and zinc (Zn) content of 12 native-floury cultivars (fresh / boiled tuber samples) and 9 native-bitter cultivars (boiled unprocessed / boiled processed tuber samples) was conduced. Additionally, the nutritional composition of the native-floury cultivars was determined after 3 and 5 months of storage under farmer conditions. A food intake study was conducted during two contrasting periods of food availability (abundance versus scarcity) in order to quantify and characterize the contribution of the potato, different cultivar categories and other food sources to the diet of children between 6 and 36 months of age and their mothers. The specific method consisted of direct measurement of food intake by weight during a 24 hour period for each household (77 households). Further, the overall nutritional status of 340 children aged between 4 and 16 years was determined. Selected cultural connotations of the highland diet were investigated through participant and ethnographic observation, surveys, and workshops.

Results show that several native-floury cultivars contain higher contents of specific nutrients (protein, iron) than those commonly reported as representative for native potato cultivars. This suggests that infraspecific diversity can make a valuable contribution to enhanced nutrition. Storage does not affect the nutritional quality of native-floury cultivars very significantly while traditional freeze-drying of native-bitter cultivars considerably reduces protein and zinc content. The research shows that malnutrition in Huancavelica is primarily a consequence of micronutrient deficiency and secondarily of insufficient total energy coverage. The highland diet is heavily dependent on staple foods, particularly potato and barley, and generally short in vegetable, fruit, meat and milk intake. The potato contributes significantly to the nutritional balance and the recommended requirements for energy, protein, iron and zinc of women and children during periods of both food abundance and scarcity. Improved and native-floury cultivars complement each other as each category provides the bulk of potatoes consumed at different moments in time. The consumption of diverse potato cultivars is entangled with cultural constructions of meals and local perceptions of preference traits and quality. The potato itself, as a food item, is no socioeconomic class marker. However, certain dishes or products and the overall cultivar diversity grown and used by a household shape perceptions of relative wealth.

Conclusions and implications

Chapter 8 highlights the main conclusions of the study and provides answers to the original research questions while taking the different system levels explored throughout the thesis into account. Selected priority areas of future research are identified and, where appropriate, links to other parts of the Andes are drawn. Furthermore, the implications for externally driven R&D oriented *in-situ* conservation efforts seeking to support dynamic and ongoing farmer-driven conservation are discussed. It is argued that the science and practice of R&D oriented *in-situ* conservation lag behind the policy commitments to its implementation and that institutional learning from diverse projects already implemented throughout the Andes and the diffusion of key lessons is essential for the success of future interventions.

Resumen

Conservación *in-situ*
Se pueden distinguir dos tipos de conservación *in-situ*: la que es conducida por los agricultores y la que se realiza a partir de intervenciones externas. La primera es el sujeto de esta tesis y se refiere a la persistencia de los recursos genéticos de papa en áreas donde las prácticas cotidianas de los agricultores mantienen la diversidad en la chacra. La segunda tiene que ver con el fenómeno más reciente de intervenciones de Investigación y Desarrollo (I&D) que intentan apoyar la conservación que realizan los agricultores. En este estudio se investiga a diferentes niveles de sistema la conservación de la papa conducida por los agricultores en los Andes centrales del Perú desde alelos, cultivares y especies botánicas hasta el nivel del paisaje, así como la interconexión con los sistemas de semilla y la alimentación humana. Se toman en cuenta dimensiones de tiempo y espacio por inferir con patrones espaciales anuales y de largo tiempo. Además, se relaciona la diversidad con tendencias promovidas por los propios agricultores y las fuerzas externas.

Objetivo y región de estudio
El estudio propone mejorar nuestro entendimiento de la conservación *in-situ* conducida por los agricultores y el contexto en el cual se realiza. El principal trabajo de campo se realizó entre 2003 y 2006 en ocho comunidades a través de un transecto norte-sur por el departamento de Huancavelica. Las comunidades fueron seleccionadas tomando como base la distribución a través del transecto, tradición de cultivo de papa, etnicidad y distancia relativa de los mercados o ciudades principales. Dependiendo de la dimensión específica de la conservación *in-situ* conducida por los agricultores que se investigaba, se utilizó una gama de diferentes métodos y herramientas.

Diversidad de especies, cultivares y alelos
En el capítulo 2 se trata la diversidad molecular, de especies y cultivares de la papa en Huancavelica a diferentes escalas de conservación: familia campesina, comunidad, y subpoblaciones geográficamente distanciadas, regionales, *in-situ* y *ex-situ*. La diversidad infraespecífica de colecciones *in-situ* fue caracterizada con el uso de listas de descriptores morfológicos y 18 marcadores microsatélites polimórficos (SSR). Las especies botánicas fueron determinadas aplicando el conteo de cromosomas para establecer la ploidía en combinación con el uso de claves morfológicas. Los datos obtenidos fueron utilizados para estadística descriptiva, análisis de (di)similitud, construcción de dendrogramas, análisis cofenético, cálculos de correlación de matrices (pruebas Mantel), y Análisis de Variancia Molecular (AMOVA).

Los resultados demuestran que los agricultores en Huancavelica mantienen altos niveles de diversidad morfológica, molecular y de especies. Se encontraron todas las especies cultivadas con excepción de *Solanum phureja* y *Solanum ajanhuiri*. Hubo mayor abundancia de especies tetraploides seguida por diploides, triploides y pentaploides. Se identificó un total de 557 cultivares que son morfológicamente únicos basándose en la caracterización morfológica de un total de 2,481 accesiones pertenecientes a 38 colecciones *in-situ*. La toma de huellas genéticas para 989 accesiones pertenecientes a 8 colecciones *in-situ* resultó en la identificación de 406 cultivares que son genéticamente únicos. AMOVA demuestra que la fuente principal de variación molecular se encuentra dentro (y no entre) de las subpoblaciones geográficamente distanciadas y pertenecientes a familias campesinas. No se encontró evidencia de erosión genética, ya que la población regional contemporánea *in-situ* y un subconjunto geográficamente restringido de la colección núcleo *ex-situ* del CIP comparten el 98.8% de la diversidad alélica. Sin embargo, las colecciones *in-situ* contienen numerosos genotipos únicos.

Biosistemática indígena

La biosistemática indígena de la papa (taxonomía folclórica, descriptores folclóricos y nomenclatura) se describe en el capítulo 3. El capítulo incluye una revisión amplia de literatura sobre el tema. Se investigó la taxonomía folclórica con el uso de ejercicios de agrupamiento con agricultores, observación participativa y comparación de grupos reconocidos por agricultores con la clasificación formal basada en descriptores morfológicos y 18 marcadores microsatélites polimórficos (SSR). El análisis del último se basó en el análisis de (di)similitud, construcción de dendrogramas y los niveles consecuentes de agrupamiento coherente por entidad taxonómica folclórica (taxón específico y varietal). Se aplicaron ejercicios etnobotánicos de listados-libres y listados-indicados con agricultores para investigar descriptores folclóricos. Para el análisis y la interpretación de los datos se utilizó estadística descriptiva. La nomenclatura se investigó aplicando encuestas de nomenclatura, observación participativa y un análisis etnolingüístico básico de nombres regionales.

La taxonomía folclórica de la papa consiste en el reconocimiento de por lo menos 5 rangos. El rango genérico folclórico está compuesto por tres taxa: *Araq Papa* (semi-silvestre / consumido), *Papa Tarpuy* (cultivado / consumido) y *Atoq Papa* (silvestre / no-consumido). Taxa específicas folclóricas (= grupos de cultivares) y taxa varietales folclóricas (= cultivares) dentro del taxón genérico de *Papa Tarpuy* son abundantes. Las categorías de uso y los criterios agroecológicos son de poca importancia para el sistema folclórico taxonómico de la papa. Las taxa varietales folclóricas se agrupan bien cuando se aplican descriptores morfológicos formales; las taxa específicas folclóricas en menor medida. Una concordancia moderada, aunque con excepciones considerables, existe entre las taxa específicas y varietales folclóricas y sus composiciones genéticas tal como caracterizadas con marcadores moleculares (18 microsatélites SSR). La coherencia de agrupamiento en un árbol de disimilitud varía para cada taxón específico y varietal folclórico considerado. Los agricultores utilizan 22 descriptores folclóricos para plantas y 15 para tubérculos, cada uno con sus caracteres reconocidos en el idioma Quechua. Los agricultores son capaces de reconocer cultivares específicos basándose únicamente en las partes superficiales de las plantas (sin exponer tubérculos). La nomenclatura es regionalmente consistente para cultivares comunes, pero inconsistente para cultivares escasos. Los nombres primarios de cultivares (sustantivo) generalmente se refieren a un taxón especifico folclórico, predominantemente a través de la referencia metafórica a la forma del tubérculo. Los nombres secundarios de cultivares (adjetivo) predominantemente hacen referencia directa al color del tubérculo.

Patrones espaciales anuales

El manejo anual espacial de la papa consiste en calendarios laborales y de cultivo, prácticas de dispersión de parcelas y manejo de interacción de genotipo por ambiente. Estas tres dimensiones del manejo de la agrobiodiversidad se exploran en el capítulo 4. Se realizó una encuesta estructurada para investigar los calendarios laborales y de cultivo. La aplicación de cartografía participativa resultó en el mapeo detallado de 601 parcelas dispersas de papa pertenecientes a un total de 122 familias campesinas. Se condujo un experimento de genotipo por ambiente (GxA) empleando 4 ambientes a través de un transecto altitudinal y 31 cultivares. Los datos obtenidos fueron analizados e interpretados usando estadística descriptiva, análisis de correlación, Sistemas de Información Geográfica (SIG), análisis *Additive Main Effects and Multiplicative Interaction* (AMMI), y análisis de variancia (ANOVA).

La distribución anual de tareas y mano de obra es, en primer lugar, una adaptación a la existencia de una sola campaña agrícola principal que depende de las lluvias y las condiciones climáticas extremas de agricultura a gran altura. El uso de tres diferentes sistemas de labranza basados en el uso del arado de pie permite a los agricultores manejar eficientemente la escasa disponibilidad de mano de obra para la preparación del suelo. Cultivares nativo-harinosos, nativo-amargos y mejorados de papa se sobreponen considerablemente en cuanto a sus patrones altitudinales de distribución. Se rechaza la noción de que estas categorías de cultivares ocupan espacios separados de producción (así llamadas "franjas altitudinales"), ya que los resultados demuestran que las diferencias entre las medianas altitudinales promedio de la distribución de área por altitud son moderadas (capítulo 4). La dispersión de parcelas se basa en una lógica combinada que resulta en una distribución atomizada de la diversidad genética de la papa a través del paisaje agrícola. Dependiendo de la comunidad, los agricultores cultivan anualmente un promedio de 3.2 a 9.1 parcelas de papa. Estas miden entre 660 a 1,576 m² y contienen hasta cien cultivares cada una. Sin embargo, la dispersión de parcelas y el manejo de altos niveles de diversidad por los agricultores no son una consecuencia directa de la adaptación de cultivares por nichos, ya que la mayoría de ellos son versátiles (capítulo 4). Más bien se sugiere que los agricultores conducen un manejo anual espacial empleando un conjunto de propiedades de tolerancia y resistencia inherentes a ciertas combinaciones de cultivares a fin de confrontar estreses bióticos y abióticos que están presentes en diferentes agroecologías. Los agricultores andinos manejan la adaptación GxA para la estabilidad conjunta del rendimiento en vez de una supuesta adaptación ambiental fina de los cultivares nativos.

Dimensiones de uso de tierra

A fin de mejorar nuestra comprensión de los posibles cambios contemporáneos que afectan la conservación *in-situ* de los recursos genéticos de la papa, se investigaron tres dimensiones específicas de uso de tierra de la papa: tendencias de uso de tierra, diseños de rotación y su intensidad, y sistemas de descanso sectorial (capítulo 5). La metodología principal de investigación involucró la cartografía participativa, usando impresiones de imágenes satelitales Quickbird de alta resolución (tamaño póster) en combinación con consultas exhaustivas a los miembros de las comunidades a partir de encuestas y encuentros de grupos focales. Se levantó información de 4,343 parcelas, incluyendo su contenido de cultivos entre 1995 y 2005. En cada comunidad se documentó la evolución sobre un periodo de 30 años (1975-2005) de los sistemas tradicionales de descanso sectorial ("puntos calientes de diversidad"). Los datos obtenidos fueron analizados usando estadística descriptiva y Sistemas de Información Geográfica (SIG). Los procesos de cambio e innovación adaptiva fueron documentados mediante la construcción de estudios de caso.

Las tendencias de uso de tierra entre 1995 y 2005 muestran que el área total dedicada a cultivares mejorados ha crecido rápidamente mientras que el área dedicada a cultivares nativo-harinosos y nativo-amargos se ha mantenido más o menos estable. Los periodos cada vez más cortos de descanso de las parcelas existentes y la incorporación gradual de los pastizales en tierras de altura sostienen el crecimiento del área. El crecimiento del área es particularmente rápido en las alturas extremas, entre 3,900 y 4,350 m. Sin embargo, los periodos de descanso en estas alturas aún son relativamente prolongados comparados con parcelas a menor altura. Los resultados demuestran que las tasas de descanso se incrementan con la altura para todas las categorías de cultivares, pero tienden a ser más bajas para los cultivares mejorados seguida por los cultivares nativo-harinosos y nativo-amargos. No hay evidencia que sostenga un reemplazamiento directo de una categoría de cultivares por otra resultando en la pérdida de la diversidad infraespecífica. La investigación acerca de la dinámica de los sistemas de descanso sectorial sobre un periodo de 30 años evidencia la desintegración gradual y el abandono de estos sistemas ricos en diversidad de cultivares. Son reemplazados por regímenes de manejo cada vez más individualistas basados en la toma de decisiones al nivel de la familia campesina. Hoy en día la organización espacial de la diversidad genética de la papa en el paisaje agrícola es cada vez más caracterizada por un patrón de distribución disperso en vez de su concentración dentro de un solo sector comunal. Donde sobreviven las rotaciones de descanso sectorial, se han adoptado innovaciones locales.

Sistemas campesinos de semilla

Los sistemas campesinos de semilla se pueden concebir como una cobertura de la diversidad genética de cultivos que determinan su distribución temporal y espacial. El capítulo 6 investiga la relación entre componentes selectos del sistema campesino de semillas (almacenamiento, sanidad y abastecimiento) y la diversidad infraespecífica de la papa en Huancavelica. Se condujo un muestreo en almacenes de semilla a fin de obtener un mejor entendimiento de la organización interna de los almacenes y cómo se relaciona eso con el manejo de la diversidad infraespecífica. Las tasas de infección de virus fueron determinadas usando muestras de tubérculo para cada uno de los cultivares diversos encontrados en los almacenes de agricultores. Se realizaron pruebas ELISA para APMoV, PLRV, PMTV, PVY y PVX. El abastecimiento de semilla se investigó a través de una serie de encuestas estructuradas y enfocadas en el intercambio familiar de semilla, el rol de los mercados y ferias de agrobiodiversidad, y el suministro de semilla después de una helada severa a escala regional. Los datos fueron analizados e interpretados con el uso de estadística descriptiva.

Los almacenes de semilla de papa contienen diferentes lotes de semilla, lo cual refleja la lógica que está en la base del manejo de la diversidad al nivel de campo y la estructura conjunta de la diversidad infraespecífica. La sanidad de la semilla conservada por los agricultores en Huancavelica es afectada por los virus transmitidos por *Diabrotica* y contacto (APMoV, PVX) mientras que los virus transmitidos por áfidos y roña son de poca importancia (PMTV, PLRV, PVY). Durante años normales, sin eventos extremos, el intercambio de semilla de cultivares nativo-harinosos es practicado por pocas familias campesinas y caracterizado por un número limitado de transacciones que involucran cantidades pequeñas de semilla de unas pocas cultivares sobre distancias relativamente cortas. Los cultivares nativo-amargos y nativo-harinosos escasos se intercambian raramente y generalmente son mantenidos y reproducidos año tras año por las mismas familias campesinas. Las comunidades que son ricas en diversidad de cultivares y ubicadas a mayor altura tienden a ser exportadoras netas de semilla. Sin embargo, la capacidad anual de abastecimiento y distribución amplia de diversidad infraespecífica del sistema campesino de semilla es limitada. Los mercados rurales tienen una capacidad descentralizada para el abastecimiento y distribución amplia de semilla de un número limitado de cultivares conocidos. Las frecuencias de intercambio de semilla en ferias de agrobiodiversidad son bajas e involucran cantidades muy pequeñas de unos pocos cultivares escasos. La resiliencia del sistema campesino de semilla para confrontar estrés regional severo es insuficiente para que las familias restauren los volúmenes y portafolios de semilla requeridas dentro de un periodo corto.

El sistema de alimentación humana basado en papa

En el capítulo 7 se investiga el rol de las papas biodiversas en la dieta humana en Huancavelica. Se condujo un análisis para determinar el contenido de la materia seca, energía bruta, proteína cruda, hierro (Fe) y zinc (Zn) de 12 cultivares nativo-harinosos (muestras de tubérculo frescas / hervidas) y 9 cultivares nativo-amargos (muestras de tubérculo hervidas no-procesadas / hervidas procesadas). Adicionalmente, se determinó la composición nutricional de los cultivares nativo-harinosos después de 3 y 6 meses de almacenamiento bajo condiciones del agricultor. Se condujo un estudio de ingesta de alimentos durante dos periodos contrastantes de disponibilidad de alimentos (abundancia versus escasez) a fin de cuantificar y caracterizar la contribución de la papa y las diferentes categorías de cultivares y otros alimentos a la dieta de los niños entre 6 y 36 meses de edad y sus madres. El método específico consistió en la medición directa de la ingesta de alimentos por peso durante 24 horas para cada familia campesina (77 familias). Asimismo, se evaluó el estado nutricional de un total de 340 niños entre 4 y 16 años de edad y se investigaron las connotaciones culturales selectas de la dieta Huancavelicana aplicando la observación participativa y etnográfica, encuestas y talleres.

Los resultados demuestran que varios cultivares nativo-harinosos tienen valores para nutrientes específicos (proteína, hierro) que son más altos de lo que comúnmente se reporta como representativo para los cultivares nativos de papa. Eso sugiere que la diversidad infraespecífica potencialmente puede hacer una contribución valiosa al mejoramiento de la nutrición humana. El almacenamiento no afecta muy significativamente a la calidad nutricional de los cultivares nativo-harinosos mientras que el procesamiento tradicional para preparar chuño con cultivares nativo-amargos reduce considerablemente su contenido de proteína y zinc. La investigación demuestra que la desnutrición en Huancavelica es, en primer lugar, una consecuencia de deficiencias de micronutrientes y, en segundo lugar, de una cobertura insuficiente de energía. La dieta Huancavelicana es altamente dependiente de alimentos básicos, particularmente papa y cebada, y generalmente deficiente en cuanto al consumo de hortalizas, frutas, carnes y lácteos. La papa contribuye significativamente al balance nutricional y a los requerimientos de energía, proteína, hierro y zinc de mujeres y niños, tanto durante periodos de abundancia como de escasez de alimentos. Los cultivares mejorados y nativo-harinosos se complementan, ya que cada categoría provee el grueso de la papa consumida durante diferentes periodos del año. El consumo de cultivares muy diversos de papa está ligado a las construcciones sociales de comidas y a las percepciones locales de criterios de preferencia y calidad. La papa en sí misma, como un alimento, no es un distintivo de pertenencia a alguna clase socioeconómica. Sin embargo, ciertos platos o productos y la diversidad total de cultivares cultivados y utilizados por cada familia campesina determinan percepciones relativas de bienestar.

Conclusiones e implicancias

El capítulo 8 resalta las conclusiones principales del estudio y brinda respuestas a las preguntas originales de la investigación mientras toma en cuenta los diferentes niveles de sistemas explorados a través de la tesis. Se identifican temas prioritarios y selectos que requieren investigación futura y, donde se considera apropiado, se reflexiona sobre los vínculos con otras partes de los Andes. Igualmente se discuten las implicancias para la conservación *in-situ* a partir de intervenciones externas orientadas a I&D que buscan apoyar la conservación *in-situ* continua y dinámica que realizan los propios agricultores. Se argumenta que la ciencia y la práctica de la conservación *in-situ* orientada a I&D van a la zaga en cuanto a los compromisos políticos que buscan su implementación. También, que el aprendizaje institucional de los diferentes proyectos que ya se implementaron en la región andina y la difusión de las principales lecciones es esencial para el éxito de futuras intervenciones.

Samenvatting

***In-situ* conservering**

Twee typen *in-situ* conservering van gewas-gerelateerde genetische bronnen kunnen worden onderscheiden: die welke door de boer zelf worden beheerd en die extern worden aangestuurd. Het eerstgenoemde type is het onderwerp van dit proefschrift: het behoud van genetische bronnen van de aardappel in streken waar de dagelijkse praktijk diversiteit op de boerderij al eeuwenlang in stand houdt. Het tweede type heeft betrekking op het meer recente fenomeen van Onderzoek en Ontwikkeling (O&O) ingrepen die conservering van genetische bronnen door boeren trachten te ondersteunen. In deze studie wordt de door de boer aangestuurde conservering van aardappelen in de centrale Andes van Peru onderzocht op verschillende niveaus: van allelen, cultivars en botanische soorten tot en met het landschap, en tevens de daarmee verbonden pootgoed- en voedselsystemen. Dimensies van tijd en ruimte worden geanalyseerd door zowel jaarlijkse als lange-termijn patronen in ogenschouw te nemen. Verder wordt de diversiteit gerelateerd aan een aantal factoren die duurzame conservatie mogelijk stimuleren of juist bedreigen.

Doelstellingen en studie gebied

De algemene doelstelling van deze studie is om ons begrip van door de boer aangestuurde conservering, en de context waarbinnen dit plaats vindt, te vergroten. Het voornaamste deel van het veldonderzoek werd uitgevoerd tussen 2003 en 2006 in acht boerengemeenschappen langs een noord-zuid transect in het departement Huancavelica. Deze gemeenschappen werden geselecteerd op basis van hun plaats en onderlinge afstand langs het transect, de traditie van aardappelteelt, etniciteit, en relatieve afstand tot belangrijke markten en steden. Afhankelijk van de specifieke dimensie van de door de boer aangestuurde gedreven conservering werd een reeks van verschillende data verzamel methoden en instrumenten gebruikt. Hoofdstuk 1 geeft een beknopte beschrijving van het onderzoeksgebied en een overzicht van de gebruikte onderzoeksmethoden.

Diversiteit van soorten, cultivars en allelen

In hoofdstuk 2 word de soorten, morfologische en moleculaire diversiteit van aardappelen in Huancavelica nader bekeken op verschillende schaalgroottes van conservering: boerenfamilies, gemeenschappen, geografisch gescheiden, regionale, *in-situ* en *ex-situ* subpopulaties. De infraspecifieke diversiteit van *in-situ* collecties werd gekarakteriseerd door gebruik te maken van morfologische descriptorlijsten en 18 polymorfe microsatellietmerkers (SSR). Botanische soorten werden gedetermineerd en benoemd met behulp van chromosoom-tellingen in combinatie met morfologische sleutels. Datasets werden gebruikt voor beschrijvende statistiek, (dis)similariteits analyse, dendrogram constructie, matrix correlatie berekeningen (Manteltesten), en Analyse van Moleculaire Variantie (AMOVA).

De resultaten laten zien dat boeren in Huancavelica een groot aantal soorten en een hoog niveau van morfologische en moleculaire diversiteit in stand houden. Alle geteelde aardappelsoorten, met uitzondering van *Solanum phureja* en *Solanum ajanhuiri*, zijn in het gebied aangetroffen. Tetraploïde soorten kwamen het meest voor, gevolgd door diploïden, triploïden en pentaploïden. In totaal werden 557 morfologisch unieke cultivars geïdentificeerd op basis van de morfologische karakterisering van 2,481 accessies behorende tot 38 *in-situ* collecties. Genetische vingerafdrukken van 989 accessies behorende tot 8 *in-situ* collecties resulteerde in de identificatie van 406 genetisch unieke cultivars. AMOVA toont aan dat de belangrijkste bron van moleculaire variantie wordt aangetroffen binnen subpopulaties en niet tussen de geografisch gescheiden en boeren familie subpopulaties. Voor genetische erosie werd geen bewijs aangetroffen: de hedendaagse regionale *in-situ* populatie en een geografisch gelimiteerde subset van

CIP's *ex-situ* core collectie delen 98.8% van de diversiteit aan allelen. Desalniettemin bevatten *in-situ* collecties vele unieke genotypen.

Inheemse biosystematiek

De inheemse biosystematiek van aardappels (volkstaxonomie, door de boeren gebruikte descriptoren en volksnomenclatuur) wordt beschreven in hoofdstuk 3. Dit hoofdstuk bevat ook een uitgebreide literatuurstudie over dit onderwerp. De volkstaxonomie werd onderzocht met gebruikmaking van groeperingsexperimenten met boeren, participatieve observatie en vergelijking van door de boeren erkende groepen met formele classificatie gebaseerd op morfologische descriptoren en 18 polymorfe microsatellietmerkers (SSR). De analyse van datasets verkregen met de laatstgenoemde methoden is gebaseerd op (dis)similariteits analyse, constructie van dendrogrammen en het clusteren per volkstaxonomische eenheid (volkstaxa op specifiek en cultivar niveau). Etnobotanische groeperingsexperimenten met behulp van "*free listing*" en "*indicated listing*" werden gebruikt om het gebruik van volksdescriptoren door boeren te onderzoeken. Voor de analyse en interpretatie werd beschrijvende statistiek gebruikt. De nomenclatuur werd onderzocht door toepassing van enquêtes, participatieve observatie en standaard etnolinguïstische analyse van regionale namen.

De volkstaxonomie van de aardappel beslaat niet minder dan vijf rangen. De algemene volksrang bestaat uit drie taxa: *Araq Papa* (semi-wild / geconsumeerd), *Papa Tarpuy* (gecultiveerd / geconsumeerd), en *Atoq Papa* (wild / niet geconsumeerd). Volkstaxa op specifiek (= cultivar groep) en cultivar niveau binnen het algemene taxon *Papa Tarpuy* zijn talrijk. Gebruikscategorieën en agro-ecologische criteria zijn maar van beperkt belang in het volkstaxonomische systeem van de aardappel. Volkstaxa op cultivar niveau clusteren goed als van formele morfologische descriptoren wordt gebruikgemaakt; volkstaxa op specifiek niveau doen dit minder goed. Er bestaat een bescheiden correlatie, hoewel met aanzienlijke uitzonderingen, tussen volkstaxa op specifiek en cultivar niveau en hun genetische compositie zoals gekarakteriseerd met moleculaire merkers (18 SSR microsatellieten). De mate van coherent clusteren in een dissimilariteitsdendrogram varieert voor elk taxon op specifiek en cultivar niveau. Boeren gebruiken in totaal 22 plant- en 15 knol-descriptoren, ieder met morfologische variabelen in de Quechua taal. Boeren zijn in staat om specifieke cultivars te herkennen aan het bovengrondse loof (zonder de knollen te zien). De nomenclatuur is op regionaal niveau consequent voor de veel voorkomende cultivars en inconsequent voor zeldzame cultivars. Primaire cultivarnamen (naamwoorden) verwijzen in het algemeen naar een volksspecifiek taxon via predominante metaforische referentie naar de knolvorm. Secundaire cultivar namen (bijvoeglijke naamwoorden) verwijzen meestal direct naar knolkleur.

Jaarlijkse ruimtelijke patronen

De aardappelteelt omvat gewas- en arbeidskalenders, ruimtelijke verdeling van de percelen, en genotype-milieu interactie management. Deze drie dimensies van agrobiodiversiteitsbeheer worden onderzocht in hoofdstuk 4. Een gestructureerde enquête werd toegepast voor onderzoek naar gewas- en arbeidskalenders. Participatieve cartografie resulteerde in de gedetailleerde kartering van 601 verspreide aardappel velden, inclusief de aanwezige cultivars, toebehorende aan een totaal van 122 boerenfamilies. Een genotype-milieu (GxM) interactie experiment in 4 milieus met 31 cultivars werd verricht met gebruikmaking van een hoogte transect. De verkregen data werden geanalyseerd en geïnterpreteerd met gebruikmaking van beschrijvende statistiek, correlatie analyse, Geografische Informatie Systemen (GIS), *Additive Main Effects and Multiplicative Interaction* (AMMI) analyse, en variantie analyse (ANOVA).

De jaarlijkse toewijzing van taken en arbeid is op de eerste plaats een aanpassing aan het belangrijkste regenafhankelijke seizoen en de klimaatsextremen van landbouw op grote hoogte. Drie verschillende voetploeg-gebaseerde systemen van landbewerking maken het voor de boeren mogelijk om schaarse arbeidskracht voor grondbewerking efficiënt te benutten. De lokale bloemige, lokale bittere en veredelde aardappelcultivars overlappen aanzienlijk in hun hoogtedistributie patronen. De stelling dat deze cultivar-categorieën gescheiden productie-arealen (zogenaamde "hoogtegordels") in beslag nemen wordt verworpen, omdat de resultaten aantonen dat verschillen tussen de hoogte-medianen voor areaalverdeling voor de verschillende cultivarcategorieën bescheiden zijn (hoofdstuk 4). Percelen worden ingedeeld volgens een gecombineerde logica welke resulteert in een "lappendeken" van genetisch divere aardappels binnen het totale landbouwareaal. Afhankelijk van de lokatie van de gemeenschap bebouwen boeren jaarlijks gemiddeld 3.2 tot 9.1 aardappelvelden van 660 tot 1,576 m² die tot honderd cultivars per veld bevatten. De indeling van de velden noch het beheer van de diversiteit door boeren is een direct gevolg van niche adaptatie, daar de meeste cultivars flexibel zijn in de aanpassing aan hun milieu (hoofdstuk 4). Er wordt gesuggereerd dat boeren jaarlijks de omgeving beheren door gebruik te maken van gecombineerde tolerantie en resistentie attributen van lokale cultivars (b.v.: door het aanplanten van verschillende cultivar combinaties) en zodoende het risico op schade door biotische en abiotische stress als het ware verspreiden over de verschillende teelt zones. Dit betekent dat boeren in de Andes genotype-milieu interactie beheren om de stabiliteit van de totale opbrengst na te streven in plaats van op specifieke milieuadaptatie van lokale cultivars aan te sturen.

Dimensies van landgebruik

Drie specifieke dimensies van landgebruik werden onderzocht om inzicht te krijgen in mogelijke hedendaagse veranderingen die de *in-situ* conservering van genetische bronnen van de aardappel beïnvloeden: tendenzen van landgebruik, types van vruchtwisseling en hun intensiteit, en sectoriële braaksystemen (hoofdstuk 5). De onderzoeksmethode maakte gebruik van participatieve cartografie met afdrukken op posterformaat van hoge-resolutie *Quickbird*-satellietbeelden gecombineerd met diepgaande consultatie door interviews en focusgroep-bijeenkomsten met leden van de gemeenschappen. In totaal werden 4,343 velden en hun gewassen tussen 1995 en 2005 in kaart gebracht. De evolutie van traditionele sectoriële braaksystemen over een tijdsbestek van 30 jaar (1975-2005) werd gedocumenteerd voor iedere gemeenschap. Data werden geanalyseerd met beschrijvende statistiek en Geografische Informatie Systemen (GIS). Processen van verandering en adaptieve innovatie werden gedocumenteerd in de vorm van case studies.

Tendenzen in landgebruik tussen 1995 en 2005 laten zien dat de totale oppervlakte die in beslag werd genomen door veredelde cultivars snel is gegroeid terwijl het areaal van lokale bloemige en lokale bittere cultivars min of meer gelijk is gebleven. Verkorte braakperioden voor bestaande percelen en de geleidelijke ingebruikname van permanente weidegronden op grote hoogte maakten deze groei mogelijk. De groei van het areaal is vooral snel op extreme hoogte tussen 3,900 en 4,350 m. Toch zijn braakperioden op deze hoogte nog relatief lang vergeleken met die van percelen in lager gelegen delen. De resultaten laten zien dat de braak-index voor alle cultivar categorieën toeneemt met hoogte, maar over het algemeen lager zijn voor veredelde cultivars gevolgd door lokale bloemige en lokale bittere cultivars. Er is geen bewijs voor een directe vervanging van één cultivar categorie door de andere die resulteert in verlies van infraspecifieke diversiteit. Onderzoek naar de dynamiek van sectoriële braaksystemen gedurende een periode van 30 jaar toont aan dat deze systemen die rijk zijn aan cultivars geleidelijk aan desintegreren en in onbruik raken. Ze worden vervangen door meer individualistische beheerssystemen die gebaseerd zijn op directe besluitvorming door de boerenfamilie. Tegenwoordig wordt het ruimtelijke distributiepatroon van genetische diversiteit van de aardappel in toenemende mate gekarakteriseerd door onregelmatige patronen in plaats van de concentratie binnen één enkele communale sector. Daar waar sectoriële braaksystemen overleven zijn lokale innovaties ingevoerd.

Boeren pootgoed-systemen

Boeren pootgoed-systemen kunnen gezien worden als een bindende kracht die de tijdsgebonden en ruimtelijke distributie van de genetische diversiteit van de aardappel van aanstuurt. Hoofdstuk 6 onderzoekt de relatie tussen geselecteerde onderdelen van het boeren pootgoed-systeem (opslag, gezondheid en voorziening) en de infraspecifieke diversiteit van de aardappel in Huancavelica. Boeren-pootgoedvoorraden werden bemonsterd om inzicht ter krijgen in de interne organisatie van de opslagplaatsen en hoe dit is gerelateerd aan het beheer van infraspecifieke diversiteit. Virusinfectie-indexen werden bepaald voor monsters van elk van de verschillende cultivars uit boerenvoorraden: ELISA tests werden uitgevoerd voor APMoV, PLRV, PMTV, PVY en PVX. Pootgoedvoorziening werd onderzocht door toepassing van een serie van gestructureerde enquêtes gericht op uitwisseling van pootgoed tussen families, de rol van gewone en speciale op agrobiodiversiteit gerichte markten, en pootgoedvoorziening na een ernstige vorstperiode. Data werden geanalyseerd en geïnterpreteerd door middel van beschrijvende statistiek.

Opslagplaatsen van boeren bevatten verschillende pootgoedpartijen welke de onderliggende logica van het beheer van cultivar diversiteit op veldniveau en de gehele structuur van infraspecifieke diversiteit weergeven. De fytosanitaire staat van cultivarvoorraden in Huancavelica wordt negatief beïnvloed door de door *Diabrotica* kevertjes en via direct contact overgedragen virussen APMoV en PVX. Virussen die door bladluizen of poederschurft worden overgedragen (PMTV, PLRV, PVY) zijn van beperkt belang. Gedurende normale jaren wordt maar door een beperkt aantal families pootgoed van lokale bloemige cultivars uitgewisseld en deze uitwisseling wordt gekarakteriseerd door weinig transacties met kleine hoeveelheden pootgoed van een gering aantal cultivars over kleine afstanden. Lokale bittere en zeldzame lokale bloemige cultivars worden weinig uitgeruild en doorgaans van jaar op jaar vermeerderd door dezelfde boerenfamilies die ze conserveren. Gemeenschappen op grote hoogte die vele cultivars bezitten zijn over het algemeen netto pootgoed exporteurs. De omvang van de jaarlijkse levering en distributie capaciteit van infraspecifieke diversiteit door het boeren pootgoedsysteem is beperkt. Reguliere markten hebben een gedecentraliseerde capaciteit om pootgoed van een beperkt aantal bekende cultivars te leveren en wijd te verspreiden. De frequentie van uitwisseling op speciale agrobiodiversiteit markten is laag en betreft over het algemeen kleine hoeveelheden van een beperkt aantal zeldzame cultivars. De veerkracht van het boeren plantgoedsysteem om ernstig regionaal gebrek aan pootgoed te overkomen is niet voldoende voor families om de gewenste hoeveelheden en variatie aan cultivars binnen een korte tijd te herstellen.

Het op aardappel gebaseerde voedselsysteem

De rol van biodiverse aardappelen in het menselijke dieet in Huancavelica wordt gepresenteerd in hoofdstuk 7. Analyses werden uitgevoerd voor de bepaling van de droge stof, bruto energie, ruwe eiwitten, het ijzer- (Fe) en zink- (Zn) gehalten van 12 lokale bloemige cultivars (verse / gekookte monsters van knollen) en 9 lokale bittere cultivars (gekookte onverwerkte / gekookte verwerkte monsters van knollen). Verder werd de voedingswaarde van de lokale bloemige cultivars bepaald na 3 en 5 maanden opslag onder boeren-condities. Een voedsel consumptie studie werd verricht gedurende twee contrasterende perioden van voedselbeschikbaarheid (overvloed versus schaarste) om zodoende de bijdrage van de aardappel, verschillende cultivarcategorieën en andere voedselbronnen in het dieet van kinderen tussen 6 en 36 maanden oud en dat van hun moeders te kwantificeren en karakteriseren. De specifieke methode omvatte directe weging van de voedselinname gedurende een periode van 24 uur per familie (van 77 families). Verder werd de algemene voedingsstatus van 340 kinderen tussen de leeftijd van 4 en 16 jaar bepaald. Een aantal specifieke culturele connotaties van het hooglanddieet werden onderzocht door participatieve en etnografische observatie, enquêtes en workshops.

De resultaten tonen aan dat verschillende lokale bloemige cultivars een hoger gehalte aan specifieke voedingsstoffen (eiwit, ijzer) bevatten vergeleken met de gehaltes die gewoonlijk representatief worden geacht voor lokale aardappelcultivars. Dit suggereert dat infraspecifieke diversiteit een waardevolle bijdrage kan leveren aan betere voeding. Bewaring beïnvloedt de voedingswaarde van lokale bloemige cultivars niet significant terwijl het traditioneel vriesdrogen van lokale bittere cultivars wel een aanzienlijke afname van het eiwit en zink gehalte veroorzaakt. Het onderzoek toont aan dat ondervoeding in Huancavelica primair een gevolg is van een tekort aan micro-elementen en secundair van onvoldoende dekking van de energiebehoeften. Het hooglanddieet is sterk afhankelijk van basisgewassen, met name aardappel en gerst, en over het algemeen deficiënt wat betreft groente, fruit, vlees en melkconsumptie. De aardappel draagt significant bij aan de voedingsbalans en de aanbevolen consumptie van energie, eiwit, ijzer en zink voor vrouwen en kinderen, zowel gedurende perioden van voedselovervloed als tijdens schaarste. Veredelde en lokale bloemige cultivars vullen elkaar aan want iedere categorie voorziet het voornaamste deel van de geconsumeerde aardappelen gedurende verschillende perioden van het jaar. De consumptie van diverse aardappel cultivars is gerelateerd met de culturele constructie van maaltijden en lokale opvatting wat betreft voorkeurscriteria en kwaliteit. De aardappel op zichzelf, als een voedsel item, is geen indicator van sociaal-economische status. Echter, bepaalde gerechten of producten en de totale cultivardiversiteit die een boerenfamilie teelt en gebruikt kenmerken percepties van relatief welzijn.

Conclusies en verder onderzoek

Hoofdstuk 8 benadrukt de belangrijkste conclusies van de studie en geeft antwoord op de originele onderzoeksvragen, terwijl tegelijkertijd ook rekening wordt gehouden met de verschillende systeemniveaus die door het proefschrift heen worden verkend. Thema's voor toekomstig onderzoek worden geprioriteerd en, waar van toepassing, verbanden gelegd met andere delen van de Andes. Verder worden de gevolgen bediscussieerd voor extern gedreven O&O georiënteerde initiatieven tot *in-situ* conservering die trachten om de continue en dynamische door de boer aangestuurde conservering te ondersteunen. Wij menen dat de wetenschap en praktijk van O&O georiënteerde *in-situ* conservering een achterstand hebben ten opzichte van de reeds gesloten politieke overeenkomsten die dit type conservatie trachten te stimuleren en versterken. Onderzoek- en ontwikkelinginstituten moeten leren van de diverse projecten die eerder in de Andes zijn uitgevoerd; dit is essentieel voor het succes van toekomstige initiatieven.

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Biography

Stef de Haan was born on 7-6-1972 in Hendrik-Ido-Ambacht, the Netherlands. He attended primary school in Giessenburg and secondary school at the "Openbare MAVO Merwecollege" (1984-1988; Hardinxveld Giessendam) and "Openbare HAVO Wijdschild" (1988-1990; Gorinchem). Between 1990 and 1996 he studied Tropical Agriculture at Larenstein International Agricultural College, Deventer. Between 1994 and 1995 he took an extended practical period in Guatemala working for CATIE (*Centro de Agronomía Tropical y Enseñanza*) and the NGO Altertec. In 1996 he joined Wageningen University to obtain his Master's degree in Ecological Agriculture in 1998 (with distinction); his thesis research on Andean tuber crops (*Ullucus tuberosus*, *Oxalis tuberosa*, *Tropaeolum tuberosum*) was conducted in Peru.

In 1998 he started working in Peru for the NGO "*Instituto Rural Valle Grande*" through Dutch development cooperation (*Centraal Missie Commissariaat* / *Vereniging Personele Samenwerking Ontwikkelingslanden*). Between 1998 and 2002 Stef worked in development projects related to the *in-situ* conservation of Andean crops and ecological production of medicinal and aromatic plants. In October 2002 he joined the International Potato Center (CIP) as a Junior Professional Officer (JPO) within the Germplasm Enhancement and Crop Improvement Division (GECI). In October 2003 he started his PhD research in combination with his work at CIP. Currently Stef continues to work for CIP as the coordinator of a Latin American Innovation Network for Crop Improvement and Varietal Dissemination (Red LatinPapa) and CIP's focal point for South and Central America.

Between 2000 and 2005 Stef coordinated several projects through the NGO *Jaqmashi*, *Stichting Samenwerkingsverband Hoogland Indianen* (SHI) and *Stichting HoPe* in the district of Tupe (Yauyos, Peru) aimed at the conservation of the endangered Jacaru language through intercultural bilingual education. Currently he is also an active member of the NGO *Grupo Yanapai* working on community based development in Chopcca, Huancavelica, Peru. Stef is married to Rosa and has a daughter (Milena).

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Training and education within the Graduate School Biodiversity

Name PhD student: Stef de Haan
Institute: National Herbarium of the Netherlands – Wageningen branch, Biosystematics Group, Wageningen University

	Credit hours
1. PhD Courses	
In-house training at CIP in high-throughput genotyping with SSR markers and molecular data analysis	80
In-house training at CIP in Geographical Information Systems (GIS) and spatial data analysis	40
2. Annual PhD meetings	20
PhD Day 2008 (Naturalis, Leiden, the Netherlands)	
3. Essays and seminars on the background and framework of the project	30
4. Literature study resulting in written report	40
5. Presentation of results at international conferences	
9th International Congress of Ethnobiology: ethnobiology, social change and displacement, Kent, UK (June 2004)	40
Annual Meeting of the Society of Economic Botany: folk botanical wisdom - towards global markets, Chiang Mai, Thailand (June 2006)	40
Solanaceae 2006: Genomics meets Biodiversity, Wisconsin, USA (July 2006)	40
Latin American meeting of INIA systems, Buenos Aires, Argentina (November 2007)	24
6. Reading course / Seminar series	
Hands-on training for NARI staff (INIAP, Ecuador; INIA, Peru) in morphological characterization, ploidy counts, ethnobotanical inquiry (2006, 2007)	80
Courses on Participatory Varietal Selection applying the M&B trial design in Ecuador, Colombia and Peru (2005, 2006)	80
Yearly organization of Annual National Potato Meetings in Peru for collaborative research INIA-CIP (2003 - 2007)	80
Workshop on advances in in-situ conservation strategies at the Annual Meeting of the Society of Economic Botany, Chiang Mai, Thailand (2006)	40
International Meeting "Seed Systems and Crop Genetic Diversity On-farm", International Plant Genetic Resources Institute (IPGRI), Pucallpa, Peru (2003)	10
7. Facultative elements	140
Total credit hours	784